EL 2

52C10

STUDENT WORKBOOK

ELECTRICITY

THEORY AND FUNDAMENTALS

NEWARK PUBLIC LIBRARY
DEC 3 1985
U. S. GOVT. PUBS.
DEPOSITORY 376

JUNE 1979

US ARMY ENGINEER SCHOOL - FORT BELVOIR, VIRGINIA

D 103.120:

READEX FICHE best copy available

TABLE OF CONTENTS

		Page
PART I	Elements of Electricity	1
PART II	Series and Parallel Circuits	51
PART III	Soldering and Splicing	57
PART IV	Safety Devices	63
PART V	Types of Wiring Systems	79
PART VI	Electrical Control Circuits	92
PART VII	Motors	112
PART VIII	Electrical Measuring Devices	148

This publication supersedes Student Workbook April 1978, ELECTRICITY.

PART I - ELEMENTS OF ELECTRICITY

1. GENERAL

For years man has been trying, with gradually increased success, to understand the effects of electricity. Some effects of electricity include: light, heat, magnetism, mechanical motion, and painful shock.

In this lesson we will study the meaning of electricity in detail to include the study of basic electric circuits (Figures 1 and 2), Ohm's Law, magnetism, electromagnetism, and transformers.

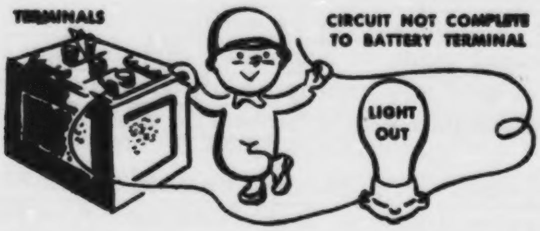

TERMINALS
CIRCUIT NOT COMPLETE TO BATTERY TERMINAL
LIGHT OUT

FIGURE NR 1 - INCOMPLETE CIRCUIT

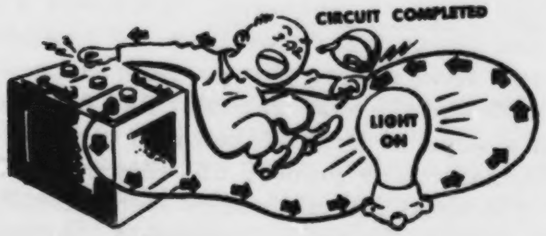

CIRCUIT COMPLETED
LIGHT ON

FIGURE NR 2 - COMPLETE CIRCUIT

This introduction to electricity will prepare you for following classes on electric motors and electric measuring devices.

2. STRUCTURE OF MATTER

Matter may be defined as any substance that has weight (mass) and occupies space. Examples of matter are the air we breath, water, cars, the clothing we wear, and our own bodies. From these examples, we can conclude that matter may be found in any one of three states -- solid, liquid, or gaseous.

a. Elements. All matter consists of one or more basic materials which we call elements. In chemistry, an element is defined as a substance that can be neither decomposed (broken up into a number of substances) by ordinary chemical changes, nor made by chemical union of a number of substances. Copper, iron, aluminum, and gold are examples of metallic elements. Oxygen, hydrogen, and sulphur are nonmetallic elements.

b. Compound. A substance containing more than one constituent element and having properties different from those of the elemental constituents is called a compound. For example, water is made up of two parts hydrogen and one part oxygen. Therefore, water is a compound. (Figure 3)

c. Molecules. A molecule is defined as the smallest particle of matter which can exist by itself and still retain all the properties of the original substance. If we take a drop of water, a compound, and divide it until we have the smallest particle possible and still have water, that particle is known as molecule. (Figure 3) An idea of the size of molecules may be obtained by imagining that a stone is first broken into two pieces, that the two pieces are broken into four pieces, and this process is carried on indefinitely. The smallest particle of stone which could be obtained by this process would be a molecule. Actually it is impossible to crush a stone into its molecules; we can only crush it into dust. One small particle of dust is composed of thousands of molecules.

d. Atoms. The atom may be considered to be the smallest part of an element that retains its identity as part of the element from which it is divided. All substances are made of one or more atoms. Just as thousands of words can be made by combining the proper letters of the alphabet, so thousands of different materials

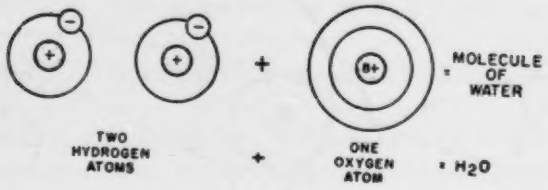


Figure Nr. 3 - Water Molecule

can be made by chemically combining the proper atoms. (Figure 3 shows that the molecule of water is made up of two atoms of hydrogen and one of oxygen.)

e. Subatomic Particles. The atom is composed of subatomic particles. There is a central body called a nucleus about which a number of smaller particles move in approximately elliptical orbits. The nucleus is composed of:

(1) Protons - positively charged particles.
(2) Neutron - neutral particles.

Around the outside of the nucleus are small moving particles called electrons which have negative charges.

3. FREE ELECTRONS

Close study of the behavior of atoms has revealed that the electrons which revolve in the outer orbits do not always remain in the same atom. Instead they move haphazardly from atom to atom. These loosely bound outer electrons, are called "free electrons". Figure Nr 4 shows schematically the travel of these free electrons in three atoms of aluminum.

Substances (like aluminum) with many free electrons in each atom are good conductors of electricity.

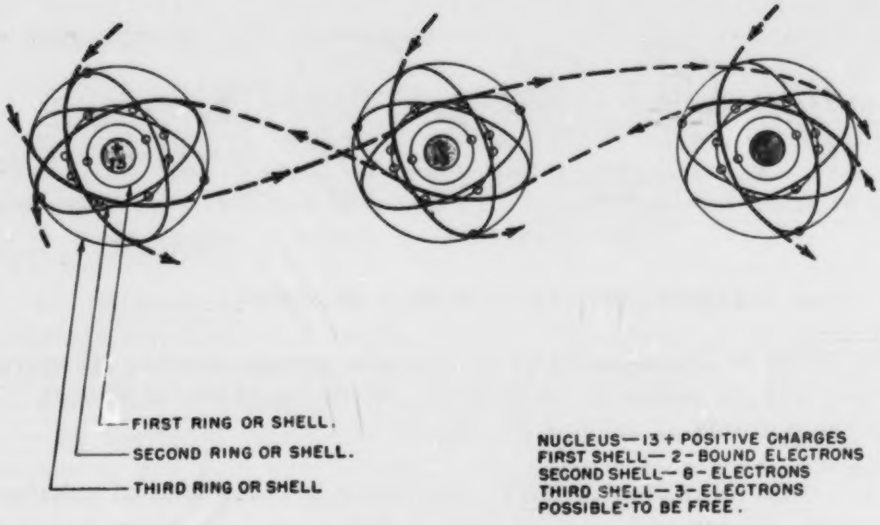

FIRST RING OR SHELL.
SECOND RING OR SHELL.
THIRD RING OR SHELL
NUCLEUS—13 + POSITIVE CHARGES
FIRST SHELL— 2-BOUND ELECTRONS
SECOND SHELL— 8-ELECTRONS
THIRD SHELL— 3-ELECTRONS
POSSIBLE·TO BE FREE.

Figure Nr. 4 - Three Atoms of Aluminum

4. SOURCES OF ELECTRICAL CURRENT

Electricity is a form of energy, and must be obtained from another form of energy.

Chemical energy is converted to electrical energy in a battery. Action among different chemicals can cause electrons to be displaced. A continued chemical reaction results in the flow of displaced electrons or electron flow.

Mechanical energy is converted to electrical energy in a generator. The work of turning the generator shaft is converted to electrical energy.

5. DIRECT AND ALTERNATING CURRENT

Direct current is said to be a current which flows in one direction only. Direct current flows from negative to positive. Direct current has a constant value and can be shown as such.

Alternating current flows from negative to positive but the force which causes the electrons to flow keeps changing from positive to negative, resulting in an electron flow that keeps changing direction The generation of A.C. will be explained later.

6. FUNDAMENTAL UNITS OF ELECTRICITY

E: voltage, or pressure, expressed as e.m.f. It is a unit of measure of the push, or pressure exerted against resistance.

I: amperage, or quantity of current. Amperage measures the amount of flow of electrons per second.

R: OHMs, resistance or opposition to flow.

7. VOLTAGE (Pressure Difference)

Voltage potential, potential difference, and electromotive force (emf) are all words for the same thing. Voltage is the measure of "pressure" which pushes the electrons through the circuit. Just as water will not flow through a pipe unless there is pressure behind it, so current will not flow through a wire unless there is voltage behind it.

In Figure 5, the pressure on the water in column A is greater than the pressure in column D. Therefore, due to the pressure difference, water will flow from B to C. Similarly, the electrical pressure (voltage) at A is greater than the electrical pressure at B and consequently electrical current will flow through the circuit.

8. AMPERAGE (Current Measurement)

Current is the "quantity" of electricity passing a particular point in a circuit in a given time. This electrical flow is measured in amperes.

Just as we could place a water meter in the pipeline and measure the number of gallons per minute going through the pipe, we can place an ammeter in the circuit and measure the number of electrons going by each minute, or second, If 3,000,000,000 electrons flow through a wire in one second, we have one ampere. If twice that many flow, we have two amperes and so on.

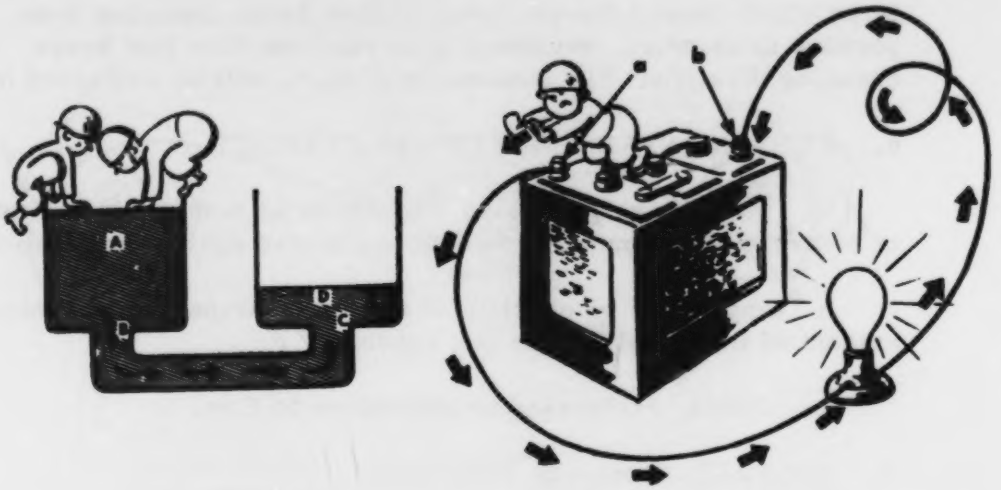


Figure Nr. 5 - Voltage (Pressure Difference)

9. RESISTANCE (Opposition to Flow)

Resistance is the opposition to electrical flow or current. Some materials allow current to flow through them easily and we say that they have a low resistance. Other materials do not allow current to pass through them and these have a high resistance (Figure 6).

Resistance also increases as the length of the wire increases, and decreases as the cross-sectional area of the wire increases.

Resistance is measured in ohms. The more ohms, the greater the resistance.

Substances with low resistance are called conductors. Those with high resistance are called insulators.

10. OHM'S LAW

The relationships of current, voltage, and resistance were first proved by George Simon Ohm (1787-1854), a German physicist. Using very poor and deficient apparatus, but the best to be had at that time, he performed a series of experiments which completely settled the questions of (1) the way electromotive force is distributed

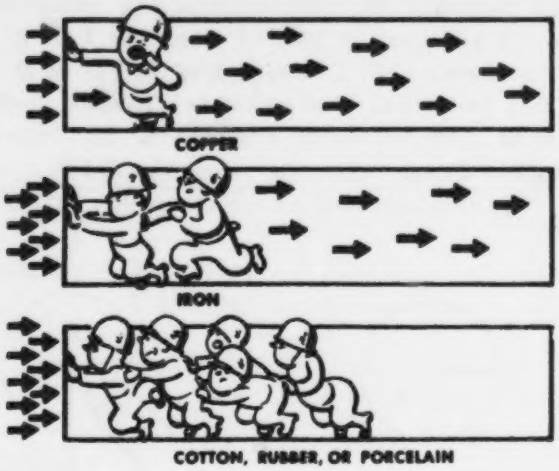


Figure Nr. 6 - Resistance

throughout a circuit, and (2) the relationships of voltage, current, and resistance. He published the results of his experiments in 1827.

a. Statement of Ohm's Law. Ohm's Law states that the current in an electric circuit is proportional to the voltage and inversely proportional to the resistance.

b. Equations for Ohm's Law. This law may be expressed by any one of three equations.

(1) $I = E/R$, or current equals the voltage divided by the resistance.

(2) $R = E/I$, or resistance equals the voltage divided by the current.

(3) $E = IR$, or the voltage is equal to the product of the current times the resistance.

c. Memory Method. The formulas for solving problems involving Ohm's Law must be learned. Do not bypass these formulas -- they must be understood and remembered. A simple aid to memorizing the Ohm's Law formulas is shown in Figure 7. Part A of this figure shows a circle with the three symbols arranged in separate spaces. If any one of the symbols is covered, the arrangement of the other two symbols forms the right-hand side of the formula for determining the value of the covered symbol. Thus, if a finger is placed over the I (B of Figure 7), E/R remains, and indicates that I is equal to E/R. If R is covered (C of Figure 7), E/I remains, and indicates that R equals E/I. In the same way, if E is covered (D of Figure 7), IR remains, and indicates that E equals IR.

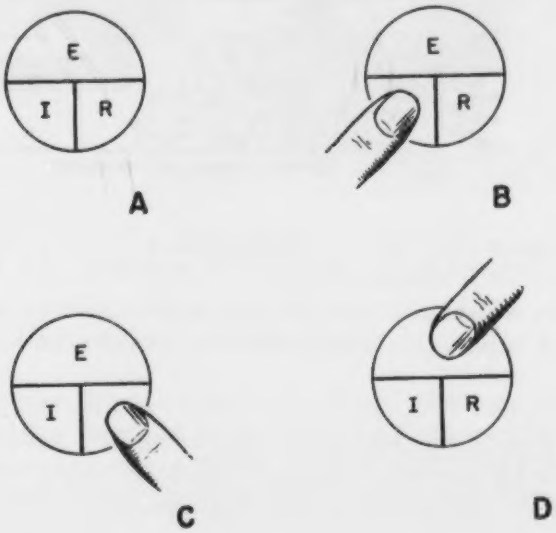


Figure Nr. 7 - Memory Aid for Learning Ohm's Law

d. Units of Measurement. It is best when solving problems with Ohm's Law to use the practical units of measurement; that is, in terms of volts, amperes, and ohms. Problems are frequently given with fractional or multiple values of these units, such as the milliampere, kilovolt, etc. When such values are given in a problem, convert all values to the basic units; volts, amperes, and ohms.

11. SAMPLE PROBLEMS

a. In a simple circuit, the applied voltage is 120 volts. The total resistance is 60 ohms. What is the current Flow?

$$I\ (\text{amps}) = \frac{E\ (\text{volts})}{R\ (\text{ohms})}$$

$$I = \frac{120}{60} = 2\ \text{amps}$$

b. In a doorbell circuit, the current flow is 40 amps, and the voltage is 120 volts. What is the resistance?

$$R\ (\text{ohms}) = \frac{E\ (\text{volts})}{I\ (\text{amps})}$$

$$R = \frac{120}{40} = 3\ \text{ohms}$$

12. MAGNETISM

This section of the manual presents many of the effects associated with magnetic force. It is magnetic force which attracts small bits of iron and steel to the end of the ordinary horseshoe magnet. It is magnetic force which swings a compass needle toward the north. Although most of the devices which utilize magnetic force can be classified as "modern", the more fundamental aspects of magnetic force (those dealing with magnetism) are as ancient as history itself.

a. Early History of Magnetism. The ancient Greeks knew that certain stones, found in the town of Magnesia in Asia Minor, had the property of attracting bits of iron. Quite appropriately, they called these stones magnetite. Legend tells of a shepherd who found to his dismay that he was unable to remove it. Another story dating back 2300 years relates how Ptolemy Philadelphos had the entire dome of a temple at Alexandria made of magnetite in order that he might suspend a statue in mid-air. The experiment was a failure. Today it is known that magnetite is an iron ore possessing magnetic qualities. In other words, magnetite is an unrefined product of nature, and is a natural magnet.

b. Magnetic Compass. The orientals learned that if a piece of magnetite were mounted or suspended in a horizontal plane and allowed to rotate, it would turn so that one particular end always pointed toward the north. The Europeans later learned of this discovery and used it as a magnetic compass to aid in navigation.

Because of this property, the piece of magnetite came to be known as a leading stone or lodestone.

c. Magnetism and Electricity. Early students of science believed that magnetism was an independent phase of science, similar to electricity but quite a different thing. Today it is generally recognized that the study of magnetism is a branch of the study of electricity.

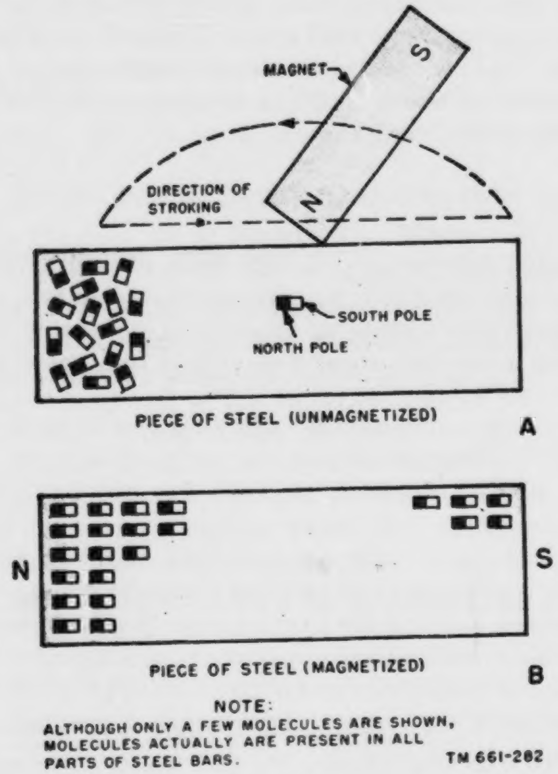
13. ARTIFICIAL MAGNETS

Although pieces of magnetite are natural magnets when taken from the earth, they now have only historic value. Better magnets can be made from pieces of iron or steel by artifical means. Artificial magnets are made in a wide variety of sizes and shapes and are used extensively in electrical apparatus. The bar magnet, horsehoe magnet, and compass needle are common types of artificial magnets.

a. Temporary Magnets. It has been found that pieces of iron and steel become magnetized when they are brought in contact with or close to a strong magnet. This process is called inducing magnetism. For example, soft iron filings will bunch in the space surrounding the end of a bar magnet and will become magnetized. Each of the filings will become a tiny magnet by induction. However, since these filings are made from soft iron, they retain their magnetism only as long as they remain in the space about the bar magnet. When the filings and bar magnet are separated, the filings lose their magnetism very rapidly. For this reason, magnets (either small or large) made from soft iron are called temporary magnets. In fact, any magnet which loses its magnetism rapidly is called a temporary magnet.

b. Permanent Magnets. If the filings used in the experiment had been made from steel instead of soft iron, the same results would have been obtained, except that the steel filings would have retained their magnetism for a longer period of time after having been separated from the bar magnet. Any magnet which retains its magnetism over a long period of time is called a permanent magnet. Thus, in the case of the steel filings, hundreds of tiny permanent magnets would have been made. The amount of magnetism retained by a material after the magnetizing force has been removed is called residual magnetism.

c. **Inducing Magnetism by Stroking.** Another method of making an artificial magnet by induction is by stroking an iron or steel bar with a strong magnet. When this method is used, it is important that all strokes be made in the same direction (Figure 8).


MAGNET
S
N
DIRECTION OF STROKING
SOUTH POLE
NORTH POLE
PIECE OF STEEL (UNMAGNETIZED)
A
N
S
PIECE OF STEEL (MAGNETIZED)
B
NOTE:
ALTHOUGH ONLY A FEW MOLECULES ARE SHOWN, MOLECULES ACTUALLY ARE PRESENT IN ALL PARTS OF STEEL BARS.
TM 661-282

A. Bar showing jumbled condition of tiny magnets before magnetization.
B. Bar showing orderly alinement after magnetization.

Figure Nr. 8 - Inducing Magnetism by Stroking

14. MOLECULAR THEORY OF MAGNETISM

A common and one of the simple theories of magnetism is that a piece of iron or steel consists of millions of tiny elementary magnets. These tiny magnets, which are so small that they cannot be seen with a microscope, may consist of atoms or molecules so aligned as to form iron or steel crystals.

a. Unmagnetized. Before a piece of iron or steel has been magnetized, these tiny magnets may be thought of as being jumbled at random with no definite order. (See A of Figure 8)

b. Magnetized. If the north pole of an inducing magnet is drawn over the bar, it attracts the south poles of the tiny magnets and turns them so that they will align themselves in a given direction. (See B of Figure 8) This definite alignment of molecular magnets will give the bar a definite north pole at one end and a south pole at the other end.

15. MAGNETIC AND NONMAGNETIC SUBSTANCES

a. Magnetic Substance. It has been shown by experiments that the invisible magnetic force which exists in the space surrounding a magnet is capable of attracting pieces of iron and steel. For this reason, iron and steel are called magnetic substances.

b. Retentivity. There are other magnetic substances which are attracted by a magnet but not so strongly as iron and steel. The more common of these substances are cobalt, nickel, and manganese. However, it is interesting to note that some of the best permanent magnets are made from alloys of these substances. The ability of a material to retain its magnetism is called retentivity. Since steel retains its magnetism longer than soft iron, steel has greater retentivity than soft iron. It follows that a material with good retentivity will have a large amount of residual magnetism, and will make a good permanent magnet.

c. Nonmagnetic Substance. Most other substances are not attracted by a magnet and are said to be nonmagnetic. Examples of these nonmagnetic substances are air, wood, paper, glass, copper, aluminum, lead, tin, and silver.

d. Magnetic Force. Magnetic force acts through any nonmagnetic substance, as can be demonstrated by moving a permanent magnet beneath a piece of paper or glass on which is sprinkled iron filings. As the magnet moves, movement of the filings can be observed. Magnetic force is mutual to both a magnet and a magnetic substance. For example, a magnet can be attracted to a firmly held piece of iron or steel just as strongly as the iron or steel is attracted to the magnet.

16. MAGNETIC POLES

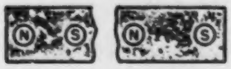
When iron filings are sprinkled over the entire area of a magnet, it can be noted that those filings which fall near the ends of the magnet will be attracted to form bunches or tufts. Scarcely any filings which fall near the center of the magnet will be so attracted. Thus, it can be seen that the bar magnet has two distinct regions, or poles. Each pole indicates the area or region where the magnetic force is greatest. The same is true of a horseshoe magnet which is, in effect, a bar magnet bent so that the poles are closer together.

a. Bar Magnet (A of Figure 9). When a bar magnet is suspended so that it is free to swing in a horizontal plane, it is found that the magnet will swing around and then come to rest with one end of the magnet pointing nearly due north. Also, it can be found that regardless of the number of times this experiment is repeated, the same end of the magnet always comes to rest pointing toward north. Thus, it can be seen that there is a difference in the direction of the magnetic forces which act at the two poles of the magnet. Long ago, when this fact was first established, it was decided arbitrarily to call the north-seeking pole of the magnet the north pole. Likewise, the south-seeking pole of the magnet was called the south pole. The designations for the poles of a magnet are still used. In fact, permanent magnets frequently are marked "N" at the north pole and "S" at the south pole.

b. Broken Bar Magnet (B of Figure 9). When a bar magnet is broken into two parts and the pieces brought into contact with iron filings, it will be found that the filings will bunch at both ends on each of the pieces, thus proving that each piece has two poles. It can also be found that one of the poles is a north pole and the other a south pole. The piece which contains the north end of the original magnet will have a south pole at the break. The piece containing the south pole of the original magnet will have a north pole at the break. Regardless of the number of times a magnet is broken, each piece will have its own north and south pole.

c. Earth as a Magnet. The fact that a suspended magnet, anywhere upon the surface of the earth, always points toward the

POLES OF BAR MAGNET
A



POLES OF BAR MAGNET
AFTER MAGNET IS BROKEN
B

Figure Nr. 9 - Bar Magnet Broken Into Two Pieces

north indicates that the earth itself is a huge natural magnet. This is illustrated in Figure 10. Note that the poles of the magnet are far below the surface of the earth, and that the magnet is somewhat inclined from the north and south geographic poles. Since the pole of any compass points to the north, that magnetic pole of the earth which is near the north geographic pole must be of south magnetic polarity, and the magnetic pole near the south geographic pole must be of north magnetic polarity, as indicated in Figure 10. The north geographic pole is referred to as true north, and the south geographic pole as true south. The deviation from the true north, which at some places is very large, is called the magnetic declination of the station. Remember that magnetic north is merely the direction in which the north end of a compass needle points.

17. ATTRACTION AND REPULSION OF MAGNETIC POLES

a. Repulsion. If a bar magnet is suspended so that it is free to swing about in a horizontal plane, the magnet normally comes to rest with its north pole pointing toward north. However, if the north pole of a second magnet is brought towards the north pole of the suspended magnet, the magnet will be pushed away. The same results will be obtained if the south pole of the second magnet is brought towards the south pole of the suspended magnet. Thus, it can be seen that the magnetic forces existing in the space surrounding like magnetic poles cause mutual repulsion of the poles.

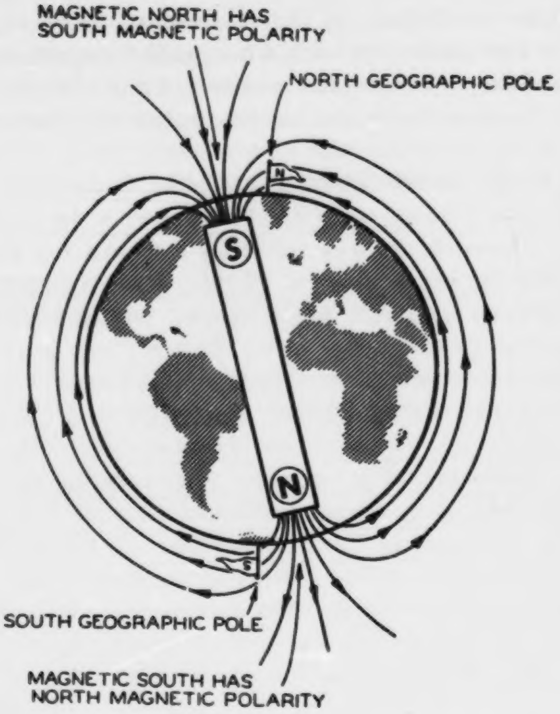

MAGNETIC NORTH HAS SOUTH MAGNETIC POLARITY
NORTH GEOGRAPHIC POLE
S
N
SOUTH GEOGRAPHIC POLE
MAGNETIC SOUTH HAS NORTH MAGNETIC POLARITY

Figure Nr. 10 - Earth as a Magnet

Another demonstration of the repulsion of like magnetic poles can be shown by the following experiment. Two strong permanent magnets are placed on a table top in a parallel position so that the north pole of one magnet is directly opposite the north pole of the other magnet. The south poles of the magnets are also opposite each other. As one bar magnet is pushed steadily toward the second magnet, invisible magnetic force pushes, or repels, the second magnet. Thus, both magnets move across the table top, one being pushed manually and the other by magnetic forces.

b. Attraction. If a bar magnet is again suspended so that it is free to swing about in a horizontal plane, it will be observed that when the north pole of a second magnet is brought toward the south pole of the suspended magnet, the two poles will be pulled together and will cling to each other until they are separated by manual force. If the south pole of the second magnet is brought close to the north pole of the suspended magnet, it will be observed that these two poles will also be pulled together, and manual force is required to separate the poles. Thus, it can be seen that the magnetic forces about the unlike poles of two magnets to be attracted.

18. LAW OF MAGNETIC FORCES

The above facts are used as a basis for the fundamental law of magnetic forces which is: LIKE MAGNETIC POLES REPEL EACH OTHER; UNLIKE MAGNETIC POLES ATTRACT EACH OTHER.

19. FACTORS AFFECTING MAGNETIC FORCE

a. Strength of Magnets. The amount of magnetic force existing in the space surrounding a magnet can be estimated roughly by measuring its lifting power. However, there are various conditions, other than the magnet itself, which will cause the lifting power to vary. Some of these conditions are:

(1) The kind of magnetic material to be lifted
(2) The shape of the material to be lifted
(3) The manner in which the material is applied to the magnet
(4) The shape of the magnet

A more accurate method for measuring the strength of a magnet, and the method most commonly used, is by measuring the force of attraction or repulsion that the magnet has on another magnet of known strength. That is, the effects that magnets have upon one another is a measure of their strength.

b. Distance Factor. The force of attraction or repulsion between two magnetic poles varies with the distance between them. When the poles are separated by a considerable distance, no visible effects are apparent. It is only after the like poles are brought close to each other that the suspended pole is repelled. Likewise, it is only after the two unlike poles are brought close together that the suspended pole is attracted. Thus, it can be seen that the magnetic force of attraction or repulsion between two magnetic poles increases very rapidly as the distance between the two poles is decreased.

20. MAGNETIC FIELD

It has been shown previously that an invisible magnetic force exists in the space surrounding a magnet and that this force is capable of acting on other magnets or magnetic substances. The space which surrounds a magnet is called the external magnetic field. (The complete field consists of the external field plus the field through the substance of the magnet.) Thus, a magnetic field may be defined as a region wherein magnetic forces act.

a. Exploring Magnetic Field With Compass. Certain facts concerning the nature of the magnetic field about a magnet can be obtained by exploring such a field with an ordinary compass. (The needle of any compass is a small permanent magnet.)

(1) When a compass is placed near the south pole of a bar magnet, the compass needle will swing about and come to rest with the north pole of the needle as close as possible to the south pole of the bar magnet. (A of Figure 11)

(2) When a compass is placed near the north pole of a bar magnet, the compass needle will swing about and come to rest with the south pole of the needle as close as possible to the north pole of the bar magnet. (B of Figure 11)

(3) When the compass is placed near the center of the bar magnet, the force existing in the magnetic field causes the compass needle's south pole to point toward the north pole of the bar magnet and the compass needle's north pole to point toward the south pole of the bar magnet. (C of Figure 11)

(4) If a number of compass needles were placed at various positions in the magnetic field of a bar magnet, each compass needle will point in a different direction according to its position in the magnetic field. Thus, it is found that a magnetic field has direction which varies from point to point. (D of Figure 11)

b. Iron Filings Experiment. A representation of the magnetic field about a bar magnet can be obtained by means of an experiment using iron filings.

(1) This experiment can be performed by placing a piece of paper over a table top and sprinkling some iron filings over a large area of the paper.

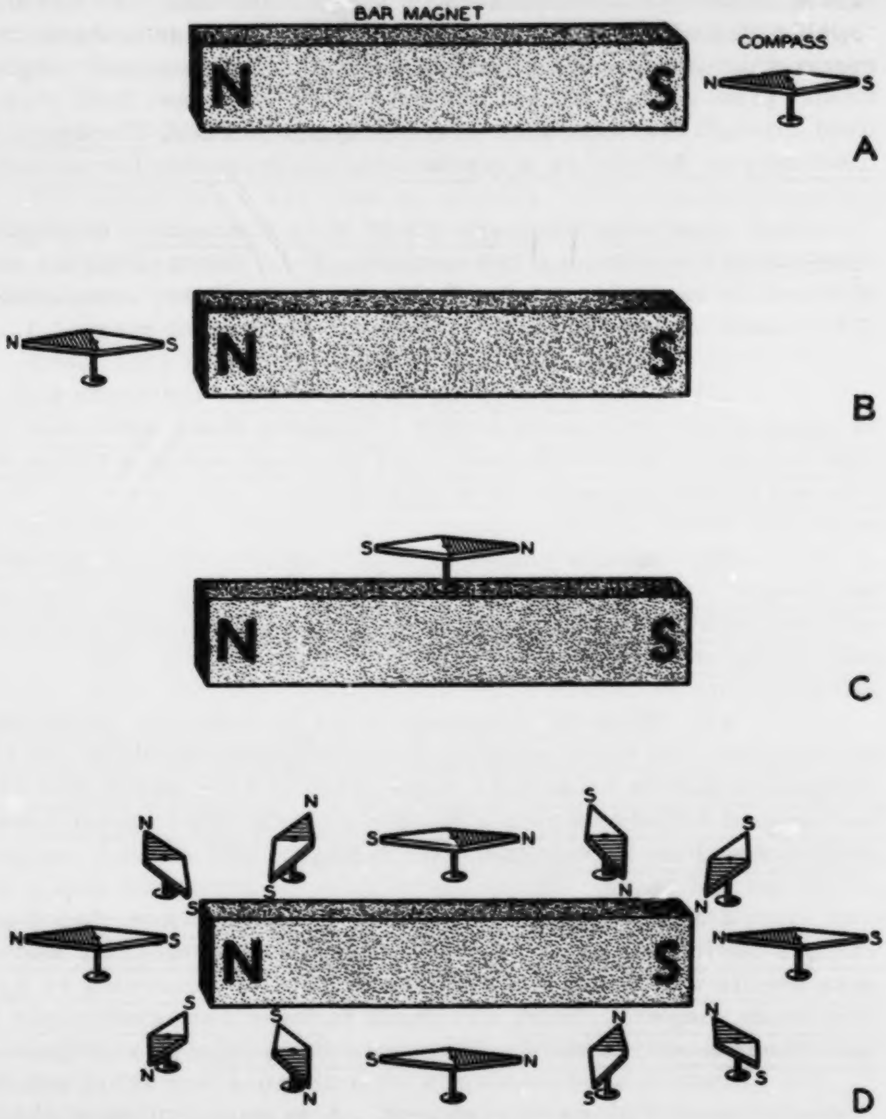

BAR MAGNET
COMPASS
N
S
N
S
A
N
S
N
S
B
S
N
N
S
C
N
S
N
S
D

Figure Nr.11- Effects of Magnetic Field on Compass Needle

(2) A bar magnet is then dropped into the center of the area containing the filings. As the magnet reaches the table, it will be noted that many of the filings near the poles of the magnet are attracted to the magnet, and slight movement of most of the other filings takes place. In short, the filings rearrange themselves because of the magnetic field about the magnet.

(3) If the table is gently tapped, the filings will completely rearrange themselves and a pattern about the magnet will appear.

(4) The explanation of why this pattern always forms is quite simple. Pieces or iron or steel become magnetized by induction when they are brought in contact with, or close to, a magnet. Thus, each of the tiny iron filings about the bar magnet becomes a small magnet with a north and south pole of its own. Each of these filings (or magnets) is affected by the direction and intensity of the magnetic field about the bar magnet, and aligns itself in the same manner as a compass needle, in response to the magnetic field.

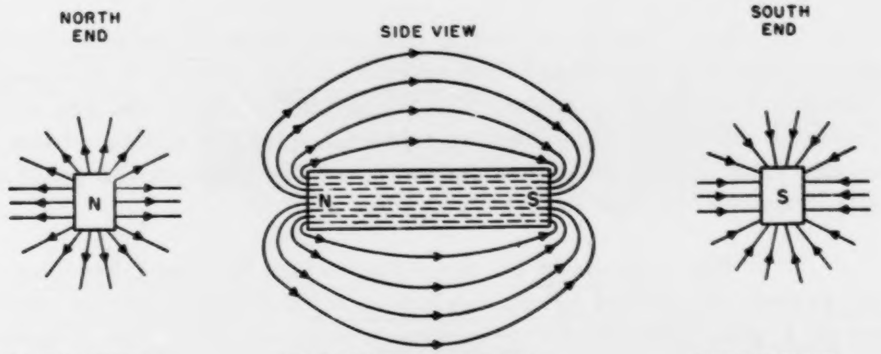
(5) The force of the magnetic field is greatest near the poles; many of the filings are attracted and adhere to the magnet, showing distinct alignment. As the distance from the poles increases, the field becomes less intense and the action of the force on the iron filings is less apparent. At the edge of the pattern, the effect on the fillings is hardly discernible.

(6) This iron filings experiment has long been used to represent the nature of the magnetic field about a magnet and it gives a conception of the direction and intensity of the magnetic forces which act in the field. However, it should be remembered that the pattern formed in this experiment is not the magnetic field itself (the magnetic field is invisible) but only a representation of the manner in which the magnetic forces in the field act on magnetic substances within the field.

c. Lines of Force. Frequently it is desired to represent, by a drawing, the direction and intensity of the magnetic field about a magnet. This can be done by drawing a picture of the pattern obtained when iron filings are placed about the magnet. However, this method is difficult and time consuming. A simpler and more commonly used method is that of arbitrarily representing the forces in a magnetic field by drawing a few lines called lines of force.

(1) Figure 6 shows the field of force about a bar magnet. By studying the lines of force, it can be seen that their over-all pattern is similar to the over-all pattern formed by the iron filings about the magnet.

(2) Note that arrowheads have been placed on each of the lines of force. Also note that the direction of each arrowhead is away from the north pole and toward the south pole of the magnet. In other words, the arrowheads indicate that lines of force leave the magnet at the north pole and enter the magnet at the south pole. Within the magnet, the direction of the force is assumed to be from the south pole to the north pole so that a continuous loop is formed by each line of force. The direction of these lines was defined arbitrarily long ago as the direction in which the north pole of a compass needle will point if placed at any point along a line of force.



FIELD OF FORCE ABOUT NORTH POLE LINES LEAVE POLE IN ALL DIRECTIONS

FIELD OF FORCE ABOUT A BAR MAGNET LINES OF FORCE SHOWN IN ONE PLANE ONLY. ACTUALLY, LINES EXTEND IN ALL DIRECTIONS AS SHOWN IN END VIEWS AND, THEORETICALLY, THROUGHOUT ALL SPACE

FIELD OF FORCE ABOUT SOUTH POLE LINES ENTER POLE FROM ALL DIRECTIONS

Figure Nr. 12 - Lines of Force About a Bar Magnet

(3) The magnetic field completely fills the space about a magnet and does not exist only in a single plane, such as along a table top. This field can also be shown to extend out to great distances and, theoretically at least, throughout all space, with the intensity of the field decreasing very rapidly as the distance is increased. Figure 12 shows how the field of force extends in

all directions about a bar magnet. The end views show the lines of force leaving the north pole and entering the south pole.

d. Characteristics of Magnetic Fields. Thus far, only the pattern of the magnetic field associated with a single bar magnet has been considered. Actually, this pattern of the magnetic field is only one of an unlimited number of possible patterns which can be produced by using one or more magnets.

(1) Opposite polarity. If the area surrounding the north pole of one bar magnet and the south pole of a second bar magnet is sprinkled with iron filings, the pattern shown in Figure 13 will be obtained.

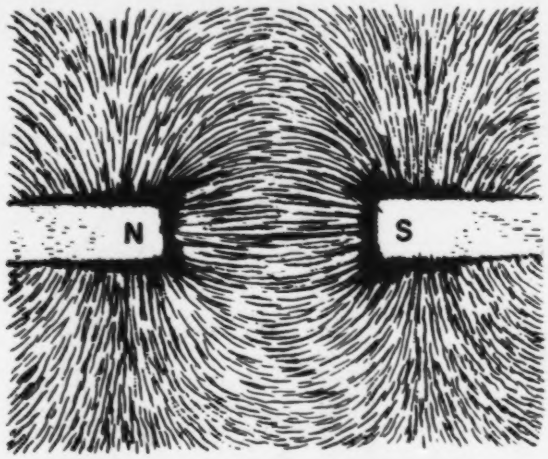


Figure Nr. 13 - Magnets of Opposite Polarity

(2) Similar polarity. If the area surrounding the north pole of one bar magnet and the north pole of a second bar magnet is sprinkled with iron filings, the pattern shown in Figure 14 will be obtained. (South poles will give the same effect.)

(3) Horsehoe magnet. Figure 15 shows the lines of force associated with a horseshoe magnet. The pattern formed by these lines of force is different from the pattern for the single bar magnet because of the physical position of the poles with respect to the magnet and to each other. Although these lines of force have a different pattern, or configuration, the characteristics of the magnetic field remain the same. That is, the magnetic field varies in intensity and direction from point to point in the field.

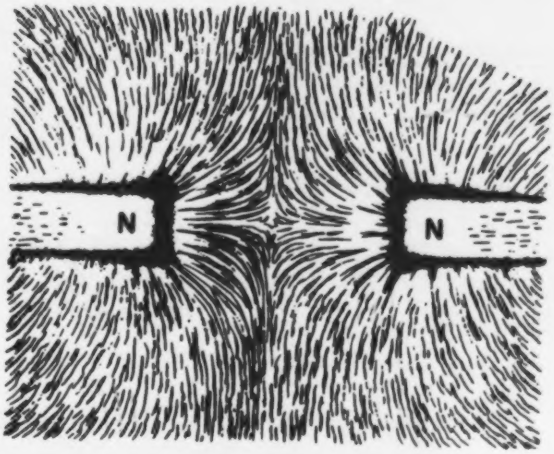


Figure Nr. 14 - Magnets of Similar Polarity

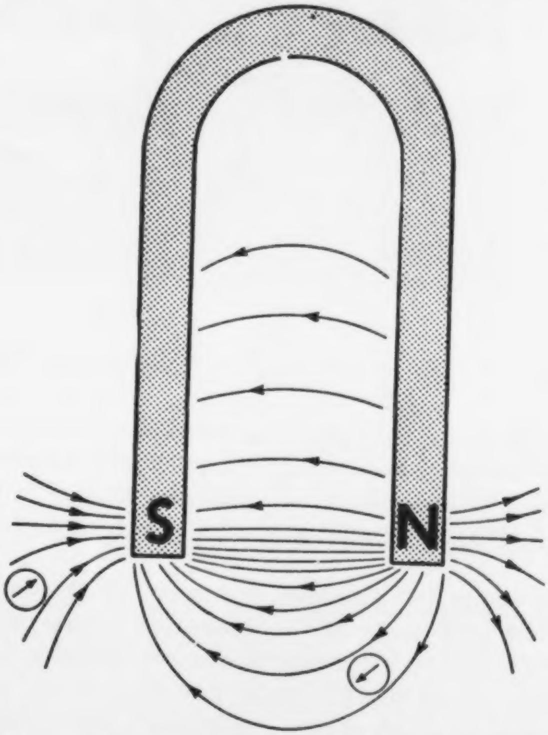


Figure Nr. 15 - Lines of Force Associated With a Horseshoe Magnet

21. ELECTROMAGNETISM

In 1819, Hans Christian Oersted, a native of Denmark and a professor of physics at the University of Copenhagen, proved that a wire carrying a current of electricity has around it a field of force which acts on a compass needle in a manner similar to the field of force around a permanent magnet. Thus, electricity produces magnetism. The operation of motors, generators, door bells, and countless other types of electrical equipment in common use today depend on the application of this discovery; that is, the relationship between magnetism and electricity (Figure 16).

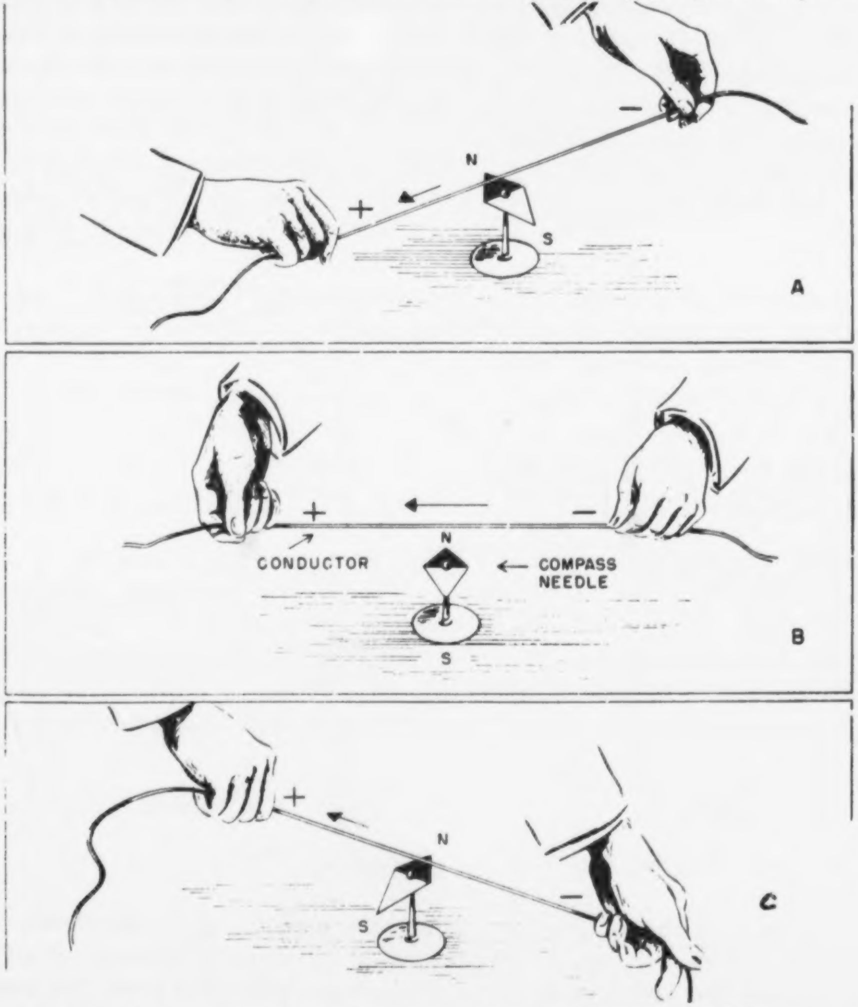


Figure Nr. 16 - Electromagnetism and Magnetic Fields

22. MAGNETIC FIELD PRODUCED BY ELECTRIC CURRENT

When magnetism is caused by an electric current flowing through a conductor, it is called electromagnetism.

a. Magnetic Field. The magnetic field produced by a current of electricity always lies at right angles to the current that produces it. The truth of this statement can be illustrated by the following experiment. Pass a current carrying conductor through a hole in a piece of cardboard or other nonmagnetic material so that the cardboard can be held horizontal (A of Figure 17). When iron filings are sprinkled on the cardboard, the filings become arranged in the form of concentric circles about the wire, thus proving that the magnetic field around the wires is circular. The direction of this field can be found by placing a compass at the various positions shown.

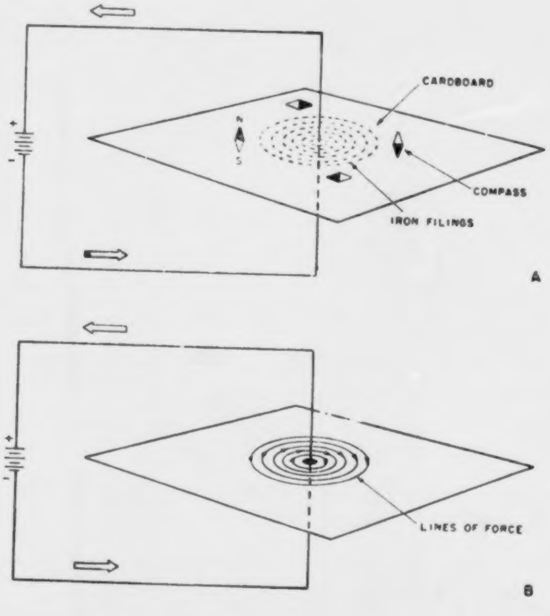


Figure Nr. 17 - Magnetic Field

b. Lines of Force. Since a magnetic field has both intensity and direction, it can be represented by lines of force. B of Figure 17 shows the lines of force closely concentrated near the conductor and gradually becoming less concentrated as the distance from the conductor increases. The lines of force are only a representation of the field since the magnetic field itself cannot be seen.

23. RELATIONSHIP BETWEEN CURRENT AND ITS MAGNETIC FIELD

Theoretically, the magnetic field of every magnet extends throughout space.

a. Strength. If one of the compasses in A of Figure 17 i moved farther away from the conductor, a point would soon be reached where the effect of the field would no longer be felt and the north pole of the compass would point to the north pole of the earth. If the current in the conductor is now increased, the compass needle will again be affected and it will point the direction of the magnetic field. From this it is evident that the strength or intensity of the magnetic field around a current carrying conductor increases when the current increases and decreases when the current decreases.

b. Direction. If the direction of the flow of current in the conductor is reversed, it will be found that the compasses in A of Figure 17 will also reverse and point in the opposite direction. This indicates that the direction of the magnetic field around a current carrying conductor is dependent on the direction of the current through the conductor. Reversing the direction of current in the conductor reverses the direction of the magnetic field.

Actually the magnetic field around a conductor extends the complete length of the conductor and not at only one point, as illustrated in A of Figure 18. Figure 18 shows a wire conductor with the lines of force indicating the direction of the field. Remember that while lines of force show direction, they are only an indication that a magnetic field is present.

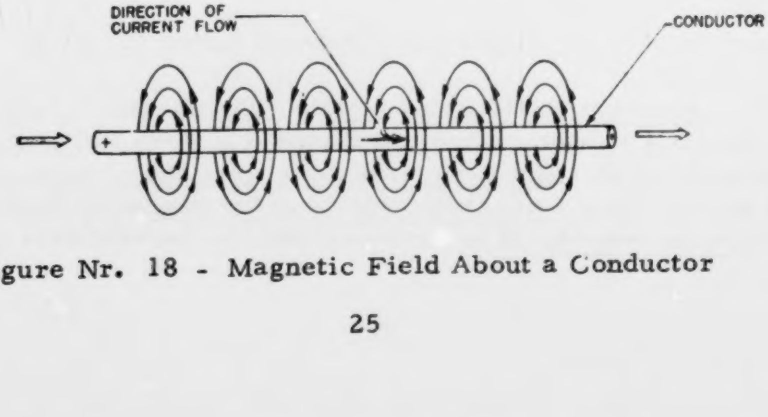


Figure Nr. 18 - Magnetic Field About a Conductor

24. INCREASING THE MAGNETIC FIELD STRENGTH

If a conductor, similar to the one represented in Figure 19 and carrying current, is bent in the form of a loop (A of Figure 19), the same circular lines of force or magnetic field surround the conductor as when it was straight. Also, when the conductor is bent into a loop, all the lines of force will enter on one side of the loop and leave on the other side of the loop (B of Figure 19). Thus, a north pole is created on one side of the loop and a south pole on the other side of the loop.

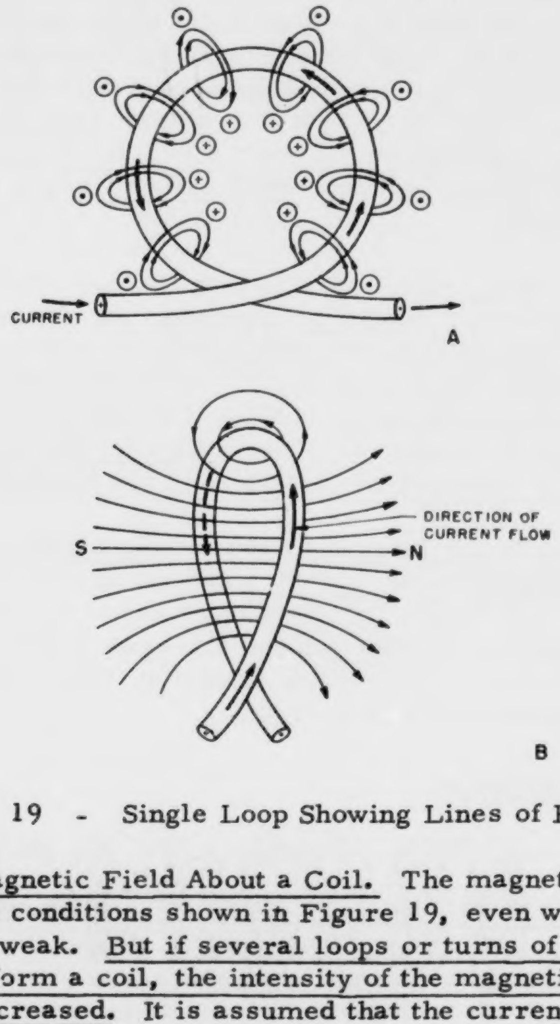


Figure Nr. 19 - Single Loop Showing Lines of Force

a. Magnetic Field About a Coil. The magnetic field resulting under the conditions shown in Figure 19, even with high currents, is relatively weak. But if several loops or turns of wire are so wound as to form a coil, the intensity of the magnetic field within the coil is increased. It is assumed that the current sets up circular lines of force around the wires in accordance with the left-hand rule. In Figure 20, the direction of the circular lines of force is therefore clockwise around the top wire and counterclockwise around the bottom wires. In the center of the coil all of the lines run in one direction, while between the turns of the coil they tend to run in opposite directions. The lines of force may be thought to be deflected from the area between the turns, thus being forced to travel the length of the entire core to complete their loops. In so doing, they increase the number of lines in the area about the ends of the coil, thereby increasing its magnetic strength.

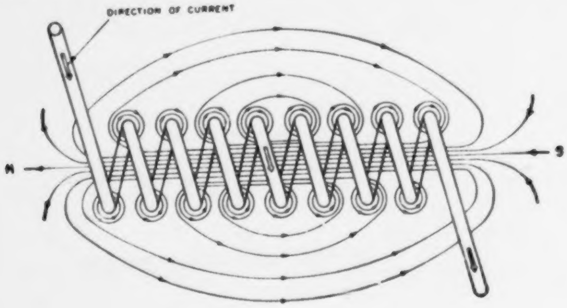


Figure Nr. 20 - Circular Lines of Force

b. Magnetic Field About a Coil With an Iron Core. Iron has the ability to gather and convey lines of force. This characteristic is called permeability. Since iron has a much higher permeability than air, it is reasonable to expect that the magnetic strength of coils can be increased by insertion of iron cores. A of Figure 21, illustrates the effect of adding an iron core on the magnetic lines of force. Notice that the lines of force extend to enter the end of the iron. Once the lines have established themselves in the core they tend to shorten, thereby exerting a force on the core. The force tends to pull or plunge the core until its center coincides with the center of the coil. B of Figure 21 shows, in solid lines, the normal position of the core in a plunger device. When an electrical current is set up in the coil, the lines of force entering the core tend to shorten, thereby pulling the core to the position indicated by the dotted lines. This action has many practical applications in the various electrical controlling devices so necessary to modern military equipment.

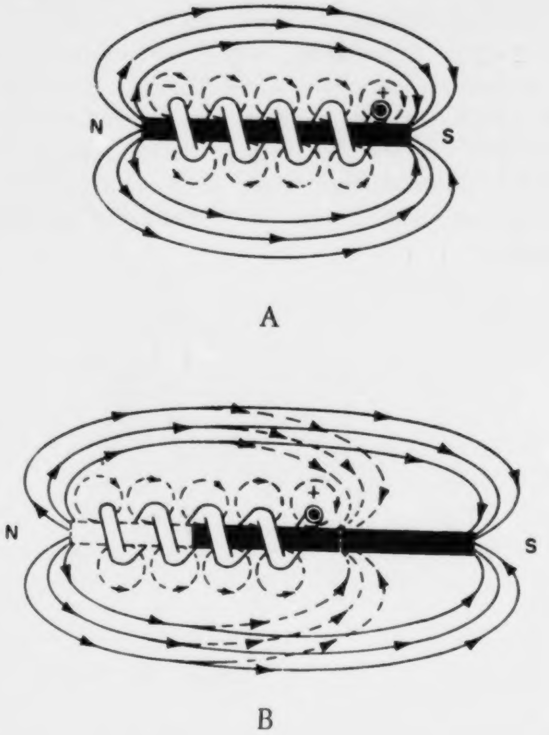


Figure Nr. 21 - Effect of Adding an Iron Core to a Coil

25. TRANSFORMERS

Transformers can be used to deliver power from the source to places that are thousands of miles away at a relatively inexpensive price. By using a transformer to step up the voltage at the source, the manufacturers can deliver this power to the consumer with very little amperage loss, thus enabling them to lower costs and still maintain a profit. Transformers can be used to change voltages on A.C. only.

a. The Objective of a Transformer. The primary objective of a transformer is to change the voltage of an alternating current source. They do NOT change D.C. to A.C. nor vice-versa.

b. Two Types of Transformers.

(1) Step-up. A step-up transformer increases the voltage, and decreases the amperage.

(2) Step-down. A step-down transformer decreases the voltage, and increases the amperage.

c. Construction.

(1) There are two coils with a pre-determined amount of turns of wire wrapped around one iron core.

(2) Primary coil. The primary coil is always called the input coil.

(3) Secondary coil. The secondary coil is called the output coil.

(4) Maintenance. Little maintenance is required because there are no moving parts.

d. Operation.

(1) Current sets up a magnetic field. Alternating current is supplied to the primary coil and at this particular point sets up a fluctuating magnetic field.

(2) Fluctuating magnetic field. The fluctuating magnetic field set up by the current cuts the wire turns of the secondary coil.

(3) Induced e.m.f. in secondary coil. By the first two procedures described, the principle of electromagnetic induction are satisfied and an e.m.f. is induced in the secondary coil.

e. Design.

(1) Step-up transformer. The primary winding of a step-up transformer will be small, and the secondary will be large.

(2) Step-down transformer. In a step-down transformer, the primary winding would be large, and the secondary would be small.

26. SUMMARY

We have learned that all matter is composed of atoms that contain tiny negative charges called electrons. We learned that there is an attraction between protons and electrons. We also learned that these electrons follow paths about the nucleus of the atom and sometimes can be made to leave one atom and join the electrons in another atom. This action, performed billions of times, produces what we call electricity.

We found that we could obtain electricity either from a chemical action or from converting mechanical energy into electrical energy and that there are two types of electrical current: direct and alternating. Direct current follows a straight path from negative to positive while A.C. changes or fluctuates in direction many times a second.

It is necessary to measure the fundamental units of electricity and these units are: E for volts or electrical pressure; I for amperes or current and R for Ohms of resistance. Ohm's Law expresses the relationship of these units in the formula $E = IXR$.

Following Ohm's Law we learned that there are materials found naturally which exhibit magnetic properties and that other materials (iron and steel alloys) can be given magnetic properties either by coming into contact with a magnet or by sending an electric current through the material.

We found also that if a conductor cuts magnetic lines of force a current is produced in the conductor.

If a coil of wire is carrying A.C. and a conductor is present in its field that alternating current is produced in the conductor. This principle allows us to transform A.C. which is to either step-up or step-down the voltage of A.C.

The above Principles of Electricity will be applied in later classes and form the basis for your understanding a sufficient amount of electricity to enable you to diagnose and repair any troubles found in a refrigeration unit which are caused by the electrical system.

STUDY QUESTIONS:

1. What is the unit of current flow? ______________________
   of potential (e. m. f.)? ______________________
   of resistance? ______________________

2. If the current is 30 AMPS and the resistance is 3 OHMS, what is the voltage?

3. What is the purpose of a transformer?

4. What is electromagnetic induction?

5. If the resistance is 1/2 OHM, and the voltage is 100 volts, what is the current flow?

STUDENT NOTES:

1. STRUCTURE OF THE ATOM.

2. SOURCES OF ELECTRICITY

3. TYPES OF CURRENT

4. FUNDAMENTAL UNITS OF ELECTRICITY

5. COMPARISON BETWEEN WATER FLOW AND ELECTRICAL FLOW

6. OHM's LAW AND UNITS

a. Formula

b. Sample Problems

7. MAGNETS

8. MAGNETIC POLES

9. MAGNETIC FIELDS

10. MAGNETIC INDUCTION

11. ELECTROMAGNETS

12. ELECTROMAGNETIC INDUCTION

13. TRANSFORMERS

14. MISC NOTES

SUPPLEMENTARY READING: ELECTRICAL SAFETY

a. General

Work on electrical circuits or apparatus of any kind is generally considered hazardous, due to accidents which have occurred, usually resulting in loss of time, partial or permanent disability, and in some cases, death. Provision for necessary safeguards and carefulness of the operating or maintenance personnel can practically eliminate most accidents. The following paragraphs or subdivisions contain the more essential, however, not all the safety rules to be applied.

b. Electrical Construction and Installation

(1) Generators, motors, control equipment, and conductors must be installed so that exposed line parts are properly guarded or protected.

(2) Rotating or moving parts of generators or motors must be properly guarded to prevent the possible catching of limbs or clothes.

(3) Control equipment such as circuit breakers, carrying 110 volts or over should be installed so that there will be sufficient room to make them readily accessible for inspection, repairs, or replacements.

(4) Main feeders and branch wiring carrying 400 volts or over should be installed in conduit or lead-covered cable. Cables with modern coverings such as neoprene would be satisfactory in many cases.

(5) Make sure the line voltage is marked plainly by signs stating the voltage of the circuit.

(6) If possible, mark lead-covered cables with nonferrous metal tags engraved with identifying numbers.

(7) Use rubber gloves and cover the rubber gloves with an additional pair of leather-protected gloves in case the rubber gloves should develop a hole or wear thin.

c. Handling of Electric Circuits

(1) Consider all voltages dangerous even though the voltage may not be great enough to produce a serious shock.

(2) When examining or making repairs on light or power circuits of any voltage, the current must be shut off by securing the main switches open and placing a tag on them marked "Men Working".

(3) Treat dead circuits the same as live circuits in case the power is accidentally turned on the circuit by another person.

(4) When locating troubles in series lamp circuits, use extreme care and before repairs are made, shut off the power.

(5) Before working on a line circuit at a point remote from the control switch which has been tagged, the conductors should be short-circuited to ground at a point on the line between the switch and where the work is to be performed.

(6) Before power is applied to a circuit for the first time, make a complete check of the circuit. If other personnel are near, instruct them to protect themselves by standing at a safe distance.

(7) Residual charges on large capacitors should be dissipated by grounding.

d. Grounding

(1) All electrical equipment such as generators, motors, conduits, switch boxes, transformers, and portable power tools and equipment must be adequately grounded when installed.

(2) The practice of grounding such apparatus is to prevent shock due to improper insulation, insulation failure, or from the current of their line circuits that may make contact with the appartus.

(3) While working on all wires, cables, or apparatus, remember that when there is voltage on a circuit, current can blow to ground, therefore, take precautions to keep the body properly insulated.

(4) Take precautions to prevent injury from shock from live circuits while working from damp or wet surfaces. Under such conditions, use additional insulation to prevent the current from grounding through the body.

(5) Grounds are both useful and undesirable. The desirable ones are easily maintained because they only require good connections. An unexpected ground, however, is a serious personnel hazard.

e. General Precautions

(1) Do not rely entirely on safety devices to prevent accidents. Make sure that the proper device is being used for the particular work being done.

(2) When working near electrical equipment, it will sometimes be necessary to rope off space to protect persons close to but not engaged in the particular operation.

(3) If the operator must leave the site for any reason, be sure to leave adequate instructions regarding the equipment to any other persons coming on the job.

(4) Rubber mats or other suitable insulation material should be used for protection while working on live circuits or when operating high tension switches.

(5) When switches are closed or opened slowly, or blades allowed to touch contacts to ascertain if power is on the line, arcs may be drawn, resulting in blinding flashes or injury.

(6) When it is necessary to pull fuses with power on the circuit of less than 500 volts, and where no switch is provided, use a LOW voltage fuse puller. Over 500 volts, use a HIGH voltage fuse puller.

(7) Iron object, such as tools or oil cans should be kept clear of field magnets to prevent their being drawn into moving parts.

f. Emergency Procedures

(1) In case of accident from electrical shock, the first step is to shut off the voltage at once if possible.

(2) If the voltage cannot be shut off, move the victim away from the power source by using ONLY a dry piece of wood or some other dry NON-METALLIC object. Do not touch the victim with bare hands.

(3) Once the victim has been removed from the power source, artifical respiration should be applied if he is not breathing. In any case, medical personnel should be called immediately.

(4) In case of electrical burns, do not touch the wound, but allow victim to rest while medical personnel are called.

(5) Whenever possible, first aid should be given by well-trained individuals.

GLOSSARY OF ELECTRICAL TERMS

Alternating Current	A current which reverses in direction at regularly recurring intervals, the total flow in one direction being equal to that in the other.
Alternator	A generator that produces alternating current.
Ammeter	An instrument for measuring electric current.
Amperage	See current.
Armature	The moving part of a dynamo or motor consisting of coils of wire around an iron core.
Bimetallic Strip	A rod or strip composed of two metals having different rates or coefficients of expansion. Upon being heated, it bends in a direction which causes the material with the greater rate of expansion to be on the outside.
Capacitor	See condenser.
Circuit	The path of an electric current. To permit a steady flow of current, the path must be complete. Commonly, a complete circuit includes a device for the production of electromotive force, connecting wires, and a device being supplied with electricity.
Condenser	A device whose capacity is its chief electrical property; a device for storing or holding an electric charge; a capacitor.
Conductor	Material that has many free electrons thus allowing electric current to flow through it readily.

Current	Rate of movement of electrons through a conductor.
Cycle	A complete sequence of events, as an alternating-current cycle.
Electromagnet	A coil of wire designed to act as a magnet as a result of carrying an electric current. It is usually wound on a soft iron core.
Electromagnetic Induction	The process of producing an electromotive force in a conductor as a result of the cutting of magnetic lines of force by a conductor.
Electromotive Force	See voltage.
Electron	Negative charge of electricity.
Frequency	The number of cycles per second, example: 60 cycles per second alternating current.
Fuse	A current limiting device designed to melt and break the circuit when a specified current is exceeded.
Horsepower	A unit of power; equal to 550 foot-pounds per second or approximately 746 watts.
Insulator	A material with few free electrons. A structure used to prevent the passage of current.
IR Drop	See voltage drop.
Kilowatt	A unit of power. 1 kilowatt = 1000 watts.
Kilowatt-Hour	A unit of work or energy. 1 kilowatt-hour = 1000 watt-hours.

Lagging Current	An alternating current whose current cycle begins later than its voltage cycle.
Leading Current	An alternating current whose current cycle begins earlier than its voltage cycle.
Magnetic Field	The space around a magnet in which the magnetic force is felt.
Magnetic Line of Force	A line representing the direction of the magnetic force in a magnetic field.
Magnetic Pole	The part of the magnet where the magnetic force is most concentrated.
Megohm	One million ohms.
Meter	A measuring device.
Micro Ampere	One millionth of an ampere.
Micro Ohm	One millionth of an ohm.
Micro Volt	One millionth of a volt.
Milliampere	One-thousandth of an ampere.
Millivolt	One-thousandth of a volt.
Ohm	The unit of resistance. It is the resistance through which a voltage of 1 volt will produce a current of 1 ampere.
Ohmmeter	Meter used to measure resistance in an electrical circuit.
Ohm's Law	In an electric circuit, or part of an electric circuit, the intensity of the current is equal to the electromotive force that drives it divided by the resistance of the circuit.

Parallel Circuit	A circuit with two or more paths for the current to take.
Permeability	That property of a material which determines how readily it conducts magnetic lines of flux.
Positive Plate	In a battery, the electrode which takes up the electrons returning from the external circuit.
Potential Difference	That difference between the electrical condition of one point in an electric circuit and that of another point which tends to cause current to flow between two points. Measured in volts.
Power	The time rate at which work is done or energy is transferred.
Primary Winding	Coil connected to the source of power on a transformer.
Proton	Positive charge of electricity.
Residual Magnetism	The magnetism which a material retains after the magnetism force which magnetized it has been removed.
Resistance	The property of a material that opposes the flow of current.
Rheostat	A resistor designed so that its resistance is readily adjustable.
Rotor	The rotating member of an electrical machine.
Secondary Winding	Transformer coil connected to the load.
Shunt Circuit	A connection or circuit of low resistance.

Step-Down Transformer	A transformer designed to lower the voltage of an alternating current.
Step-Up Transformer	A transformer designed to raise the voltage of an alternating current.
Series Circuit	A circuit with only one path for the current.
Stator	The stationary part of an electrical machine.
Three-Phase Circuit	A circuit carrying three alternating currents whose cycles begin one after the other.
Transformer	A device used to change the voltage of an alternating current.
Volt	The unit of electromotive force, potential pressure, or voltage which produces a current of one ampere in a circuit having a resistance of 1 ohm.
Voltage Drop	Term applied to the loss of voltage in forcing current through any portion of a circuit.
Voltmeter	An instrument for measuring electromotive force in volts.
Watt	A unit of power.
Wattmeter	An instrument for measuring electric power.

WIRING SYMBOLS

WIRING SYMBOLS (Cont'd)

PART II - SERIES AND PARALLEL CIRCUITS

1. GENERAL

In refrigeration work it is often necessary to use two or more pieces of equipment in one electrical circuit. These pieces of equipment may be connected in a number of different ways. All circuits however intricate, may be divided into three general classes; series circuits, parallel circuits, and series-parallel circuits.

2. SERIES CIRCUIT

A series circuit is one in which the resistance or other electrical devices are connected end to end so that the same current flows in each part of the circuit. Almost everyone is familiar with the string of Christmas tree lights in which all of the lamps go out when any one of the lights burn out. These lamps are connected in series

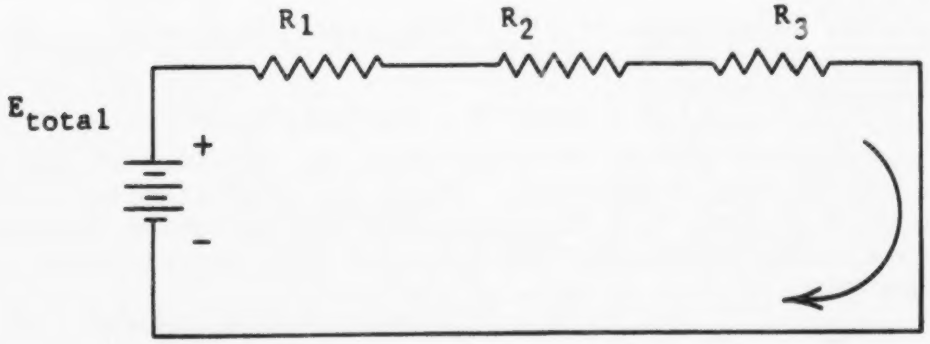


Figure 1 - Series Circuit

The three laws of a series circuit summarized below, should be committed to memory:

a. The total resistance is the sum of the individual resistances.

b. The same current flows in each part of the circuit.

c. The sum of the voltage drops across the individual resistors is equal to the total or applied voltage.

The following formulas are very helpful in solving electrical circuits:

Total Resistance: $R_{total} = R_1 + R_2 + R_3$

Total Current: $I_{total} = \frac{E_{total}}{R_{total}}$

Voltage drop at resistor No. 1: $E_1 = I \times R_1$

Voltage drop at resistor No. 2: $E_2 = I \times R_2$

Voltage drop at resistor No. 3: $E_3 = I \times R_3$

Total Voltage: $E_{total} = E_1 + E_2 + E_3$

3. PARALLEL CIRCUITS

In a series circuit only one path was provided through which the current might flow. There are also circuits which will provide more than one path through which current may flow. These circuits are known as parallel circuits (Figure 2).

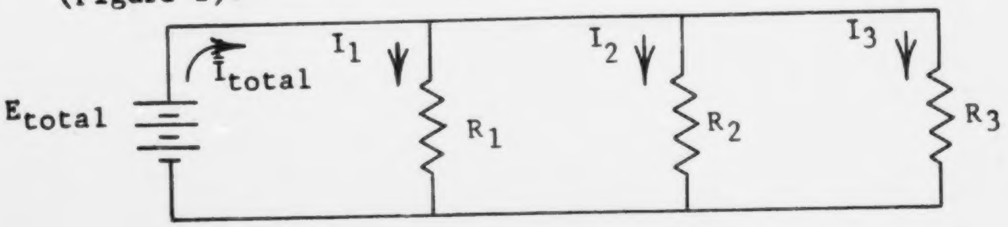


Figure 2 - Parallel Circuit

The three laws of a parallel circuit summarized below, should be memorized:

a. The same voltage is across each resistor.

b. The total current in a parallel circuit is equal to the sum of the currents flowing in the individual branches.

c. The total resistance is always less than the smallest individual resistance in the circuit and can be found by dividing the applied voltage by the total current.

$$\text{Total Voltage} = E\ \text{total} = E_1 = E_2 = E_3$$

$$\text{Current through Resistor No. 1} = I_1 = \frac{E}{R_1}$$

$$\text{Current through Resistor No. 2} = I_2 = \frac{E}{R_2}$$

$$\text{Current through Resistor No. 3} = I_3 = \frac{E}{R_3}$$

$$\text{Total Current} = I\ \text{total} = I_1 + I_2 + I_3$$

$$\text{Total Resistance} = R\ \text{total} = \frac{E\ \text{total}}{I\ \text{Total}}$$

$$\text{Total Resistance}\ \frac{1}{R\ \text{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

4. SERIES-PARALLEL CIRCUITS

Series-parallel circuits consist of groups of parallel resistors in series with other resistors (Figure 3). Any leg of a parallel group may consist of two or more resistors in series (Figure 4). Series-parallel circuits may be solved by application of the rules already given for simple series and parallel circuits. To do this, the series-parallel circuits is reduced to an equivalent, simplified circuit. Each group of parallel resistors is first replaced by its equivalent single resistance, and the entire circuit is then treated as a series circuit.

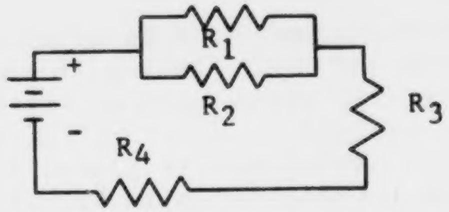


Figure 3 - Series-Parallel Circuits (Four Resistors)

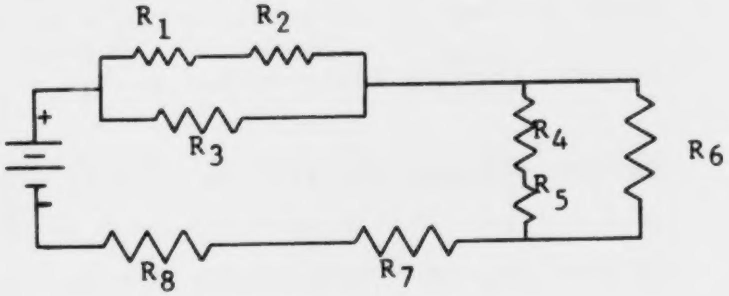


Figure 4 - Series Parallel Circuits (Eight Resistors)

STUDY QUESTIONS:

1. How is the total resistance of a series circuit determined if the values of the individual resistors are known?

2. What does the sum of the separate voltage drop in a series circuit equal?

3. Why are lamps in houses nearly always connected in parallel?

4. Is the total resistance of a circuit increased or decreased as equipment is added in parallel?

5. Does the current returning to the source of emf always equal the current leaving the source?

NOTES:

1. DEFINITION OF CIRCUIT

2. TYPES OF CIRCUITS

a. Series circuit

b. Parallel circuit

c. Series-parallel circuit

PART III - SOLDERING AND SPLICING

Skill in splicing wires is necessary if one wishes to build good and safe circuits. A splice if loose or not insulated properly often causes arcing, which may either destroy the splice or start a fire.

A few important rules to remember when splicing conductors are:

1. Remove insulation and clean wire before making splice.

2. Make the splice mechanically secure so it will not work loose and cause arcing.

3. Solder splice (if possible).

4. Insulate the splice to equal the insulation on the wires.

The National Electrical Code ruling on splices for wires carrying current at 110 volts or greater is:

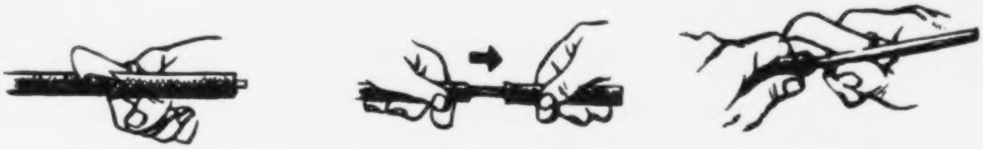
"Wires shall be so spliced or joined together as to be mechanically and electrically secure without solder. The joints shall then be soldered, unless made with a splicing device, and shall be covered with an insulation equal to that on the wires."

1. WIRE-TO-TERMINAL CONNECTIONS

Screw terminals and solderless or solder connectors are used to attach wires to terminals, such as switches ore receptacles.

Removing Insulation (Fig 1)

Cut through insulation, holding knife at a 30° angle to wire. Take care not to nick wire; this will weaken it and lower its current carrying capacity. When insulation is completely cut, pull it off wire. Scrape off any insulation sticking to wire.

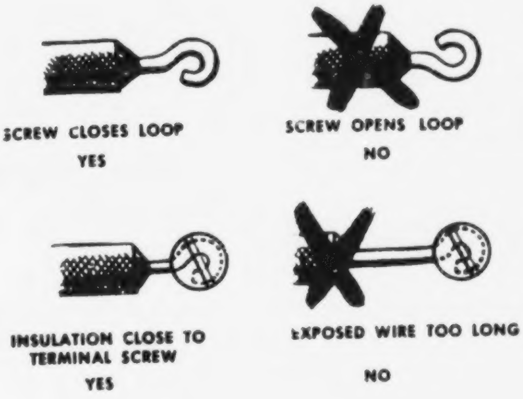


Cut Installation Pull Off Installation Clean Wire

Figure Nr. 1 - Removing Insulation

2. SCREW TERMINALS (Fig 2)

To attach wires to screw terminals, form a loop in end of wire; put wire loop around screw; tighten screw. Make loop so screw turns against loop, closing it when screw is tightened. Insulation must be close to the terminal screw. Do not leave a long exposed portion of wire next to terminal.



SCREW CLOSES LOOP
YES

SCREW OPENS LOOP
NO

INSULATION CLOSE TO TERMINAL SCREW
YES

EXPOSED WIRE TOO LONG
NO

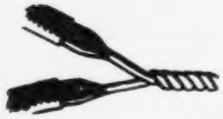
Figure Nr. 2 - Screw Terminals

Removing Insulation

Cut insulation the same as sharpening a pencil; remove it and clean wire. If outer braid covers wire, cut it 1 or 2 inches back of first cut and remove braid. Take care in last cut to cut only outer braid.

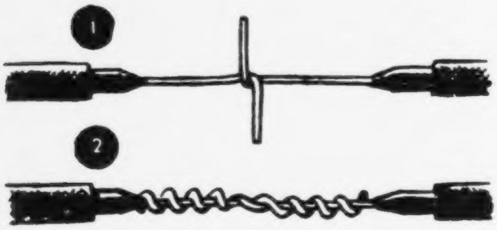
3. TYPES OF SPLICES

a. Pigtail Splice



If they are not under tension, wires may be spliced by twisting them together in a pigtail.

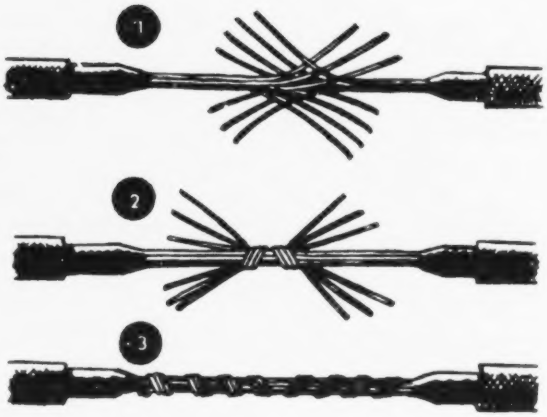
b. Western Union Splice



To splice two single-strand wires under tension, cross them (step 1) and then twist each wire at least five turns on the standpart of the other (step 2).

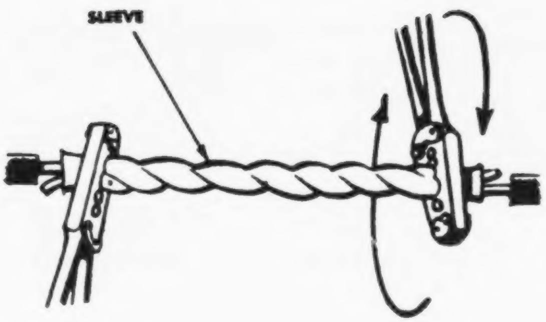
c. Stranded Splice

To splice stranded wires under tension, separate strands (step 1); push two ends together (step 2); and wrap each strand separately around opposite strands (step 3). By carefully wrapping all strands a neat, tight splice is made.



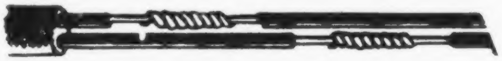
d. Sleeve Splice

To make a sleeve splice, insert cleaned, scraped portion of



each wire into a sleeve. Grip each end of the sleeve with a clamp. Hold one clamp stationary and twist the other five to seven revolutions to tighten the splice. Sleeves are used on transmission lines and pole-to-building wiring.

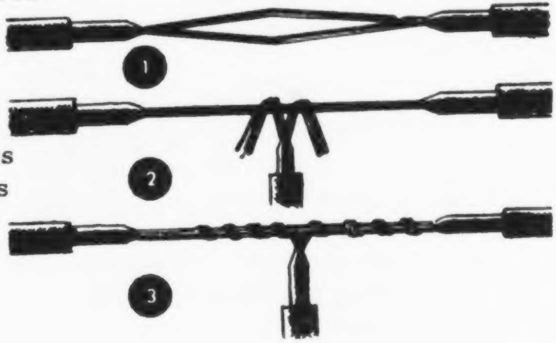
e. Lamp Cord Splice



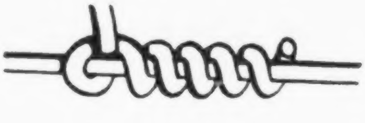
To splice lamp cord, stagger the joints in the two wires and make a tension splice on each wire.

f. Tapping Multi-Strand Wires

To tap standard multi-strand wires, separate strands of the main wire (step 1); thread tap wire through separated strands (step 2); separate tap wire strands (step 3); and wrap separated tap wire strands around main wire.

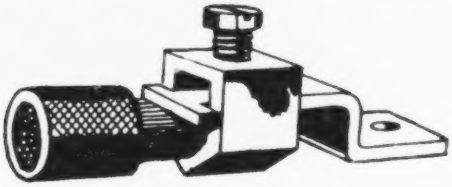


g. Single Wire Tap or "T"



To tap single-strand wires, lay tap wire under and wrap it around the main wire once. Then cross top wire under itself and take 5 to 10 turns around main wire. The connection forms half a girth hitch on the main wire, making a positive tie.

h. Solderless Connectors



To use a solderless connector, put clean end of wire in connector and tighten screw. Exposed wire outside the conductor must be short.

STUDY QUESTIONS:

1. Why is it important that conductors be properly spliced?

2. What are three common splices?

3. Where is the Western Union splice used?

4. What is the purpose of reinsulating spliced wires?

5. Where is the pigtail splice used?

NOTES:

1. SPLICING

2. SOLDERING

3. TAPPING

PART IV - SAFETY DEVICES

GENERAL

In our previous lesson we learned that all matter is composed of atoms. Some atoms have electrons moving about them which are loosely held and can be broken loose easily. These electrons are called free electrons.

A material which has a large number of free electrons will allow the current to flow easily and is classified as a conductor. All metals are conductors of electricity to some extent, but some are much better conductors than others. Silver, copper, and aluminum are examples of good conductors with silver being the best conductor of the three metals.

An insulator is a material or combinations of materials the atomic structure of which prevents practically any movement of electrons. In other words this material has very few free electrons and, therefore, does not conduct electricity easily. No material known is a perfect insulator through which electricity cannot be forced but there are materials which are such poor conductors that for all practical purposes they are classed as insulators. Porcelain, glass, air, dry wood, rubber, and oil are insulating materials. Insulation material is used so that electrical equipment can be handled safely and to prevent leakage and power loss.

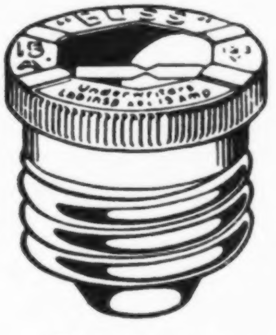
Electric wires are constantly being heated by the current flowing through them. If too much current is allowed to pass through these conducting wires, they may become so hot that they will burn away their insulation and start a fire. To avoid the danger of overloading the lines, fuses or other current limiting safety devices are used. There are several types of current limiting safety devices in use. These are as follows:

1. FUSES (Fig 1)

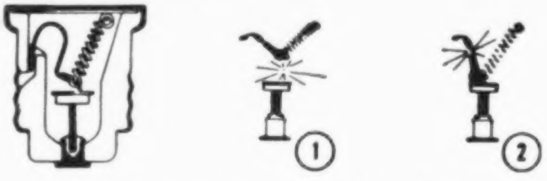
These consist of a small strip of material which has a fixed resistance and a low melting point. The fuse is connected in series with the circuit that it is to protect. As soon as the current grows dangerously large, the fuse becomes hot and melts, thus breaking the circuit. This simple fuse is available in either the plug or cartridge type.

2. TIME DELAY FUSES

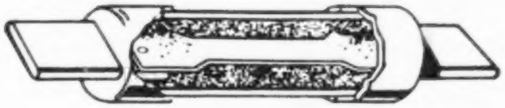
Time delay fuses (commonly called fusetrons or fusestats) are available in either the plug or cartridge type. They operate on the solder pot principle as shown below



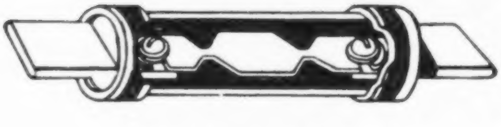
Plug Type



Plug types with time lag

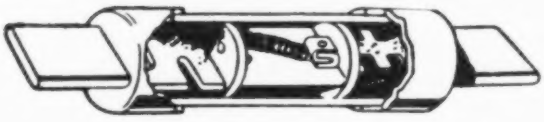


NONRENEWABLE FUSE



RENEWABLE FUSE

Knife Blade Types



Knife Blade Type with Time Lag

Figure No. 1 - Fuses

The heavy fuse link (similar to the link in a normal fuse) is sized large enough so that it will not blow on a motor starting current. However, a current overload heats the small pot of solder. If even a slight overload continues for any length of time, the solder will soften and release the spring, thus opening the circuit (1). Since motor starting currents do not last long enough to melt the solder; the time lag fuse does not open. In case of a short circuit, however, the fuse link blows just as an ordinary fuse (2).

3. CIRCUIT BREAKERS

Circuit breakers are operated by an electromagnet. The load current passes through the magnet coil, if the current is too high, the electromagnet will pull the switch open. Circuit breakers are made in many different styles and can be constructed either with or without the time delay feature.

TIPS AND TECHNIQUES:

The following information will be of assistance to you in electrical work.

Wire Sizing:

WIRE TABLE

Approximate Dimensions and Resistance of Commercial Copper Wire
American Standard

(Brown & Sharp) Wire Gage

B&S Gage No.	Diameter Bare Wire In.	Safe Carrying Capacity, Amperes Rubber Insulation	Other Insulation	Ohms per 1,000 Ft. 70°F	167°F
0	.325	105-160	127-325	0.100	0.119
1	.289	91-136	110-280	.127	.150
2	.258	80-118	96-241	.159	.190
3	.229	69-101	83-211	.202	.240
4	.204	60-87	72-180	.254	.302
5	.182	52-76	63-158	.319	.381
6	.162	45-65	54-134	.403	.480
8	.128	35-48	41-100	.645	.764
10	.102	25-35	31-75	1.02	1.21
12	.081	20-25	23-57	1.62	1.93
14	.064	15-20	18-43	2.57	3.07
16	.051	6	10	4.10	4.88
18	.040	3	6	6.51	7.77
24	.020	-	-	26.2	31.2
30	.010	-	-	106.	126.
36	.005	-	-	423.	505.

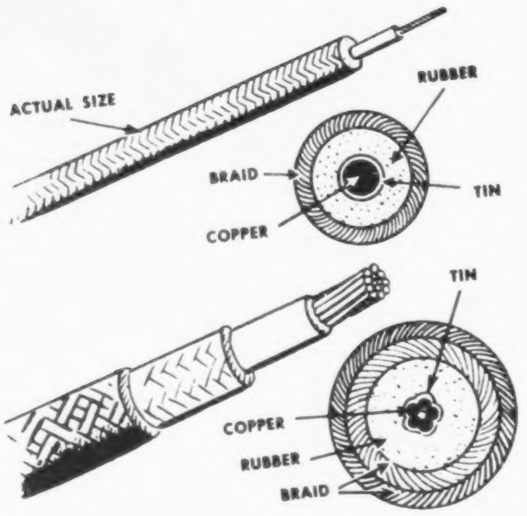


Figure No. 3 - Rubber-Covered Wire

Simply constructed rubber-covered wire consists of a copper conductor, a thin layer of tin, a layer of rubber, and a layer of cotton braid impregnated with weatherproofing and fireproofing compound. This is the usual construction for No. 8 wires and smaller. A double covering of braid is usually put on No. 6 wires and larger. (Fig 3)

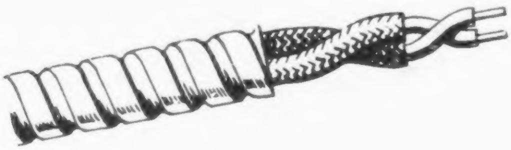


Figure No. 4 - Metallic Armored Cable (BX)

A flexible sheet-steel armor is wrapped over two or more rubber-covered wires. This cable is used extensively for interior building wire, (Fig 4) and is called metallic armored cable (BX).

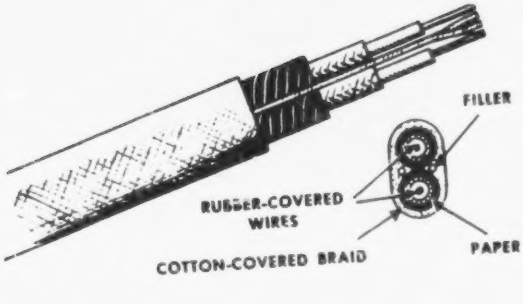

FILLER
RUBBER-COVERED WIRES
PAPER
COTTON-COVERED BRAID

Figure No. 5- Nonmetallic-Sheathed Cable

Nonmetallic sheathed cable is made up of two or more rubber-covered wires, is protected by asphalt-impregnated layers of waterproof and weatherproof cotton and paper. The cable is normally used in building wiring. (Fig 5)

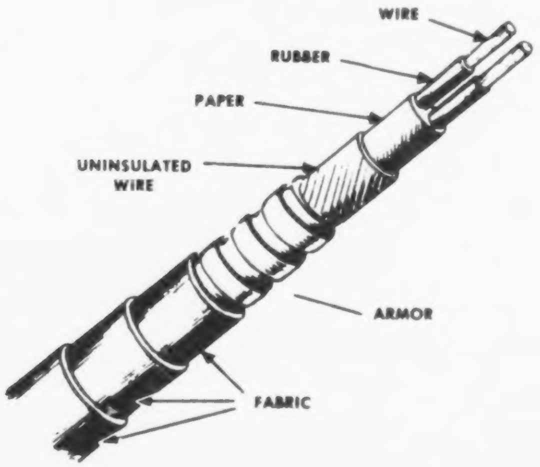

WIRE
RUBBER
PAPER
UNINSULATED WIRE
ARMOR
FABRIC

Figure No. 6 - Service-Entrance Cable

Service entrance cable (Fig 6) consists of two rubber-covered wires wrapped in a third uninsulated wire. Metallic armor covered with several layers of fabric are sometimes added for extra protection. The uninsulated wire serves as a ground when connected to a grounding pipe, or as a neutral wire.

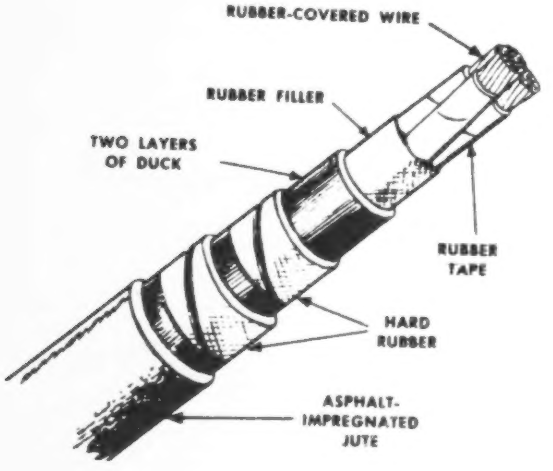

RUBBER-COVERED WIRE
RUBBER FILLER
TWO LAYERS OF DUCK
RUBBER TAPE
HARD RUBBER
ASPHALT-IMPREGNATED JUTE

Figure No. 7 - Armored Parkway

Armored parkway cable (Fig 7) consists of one, two or three rubber-covered wires, covered with a layer of rubber tape and filler, two layers of asphalt-filled duck, two layers of hard rubber, and a layer of asphalt-impregnated jute. It can be buried underground without further protection.

CONDUIT AND FITTINGS

Steel Conduit

Conduit is thin, steel pipe which bends easily. It has smooth inside walls so wire insulation is not broken. Two types of conduit used are the standard (rigid) conduit and thin-walled conduit.

NUMBER OF WIRES ALLOWABLE IN VARIOUS SIZED CONDUITS[1]

SIZE OF WIRE	NUMBER OF WIRES IN ONE CONDUIT								
	1	2	3	4	5	6	7	8	9
18	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4
16	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4
14	1/2	1/2	1/2	1/2	3/4	3/4	3/4	1	1
12	1/2	1/2	1/2	3/4	3/4	1	1	1	1 1/4
10	1/2	3/4	3/4	3/4	1	1	1 1/4	1 1/4	1 1/4
8	1/2	3/4	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4
6	1/2	1	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2
4	3/4	1 1/4	1 1/4	1 1/2	2	2	2	2	2 1/2
2	3/4	1 1/4	1 1/2	1 1/2	2	2	2 1/2	2 1/2	2 1/2
1	3/4	1 1/2	1 1/2	2	2	2 1/2	2 1/2	3	3
1/0	1	1 1/2	2	2	2 1/2	2 1/2	3	3	3
2/0	1	2	2	2 1/2	2 1/2	3	3	3	3 1/2
3/0	1	2	2	2 1/2	3	3	3	3 1/2	3 1/2
4/0	1 1/4	2	2 1/2	2 1/2	3	3	3 1/2	3 1/2	4

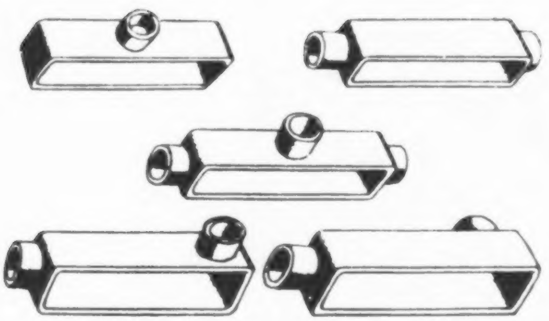
RUBBER-COVERED OR WEATHERPROOF WIRE

Condulets

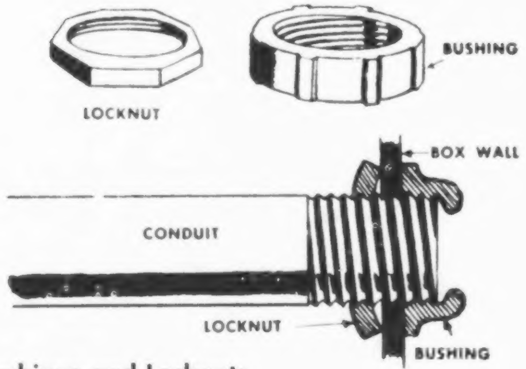
Condulets are small outlet boxes with threaded inlets to take conduit pipe.

Bushings and Locknuts

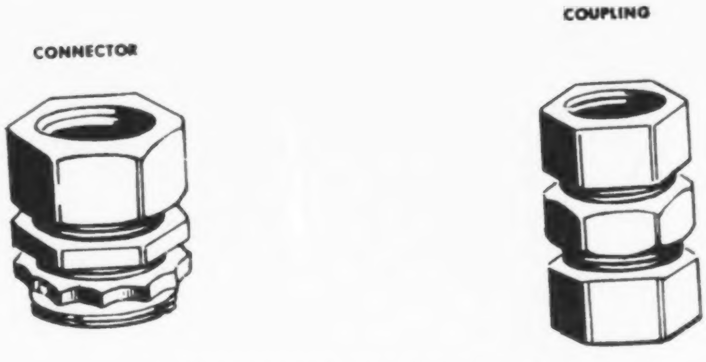
Bushings and locknuts are fittings used to dead-end conduit in an ordinary outlet box.



Condulets


LOCKNUT
BUSHING
BOX WALL
CONDUIT
LOCKNUT
BUSHING

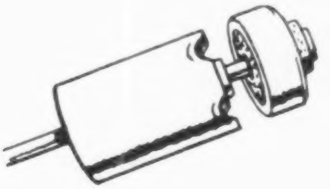
Bushings and Locknuts



Connectors and Couplings

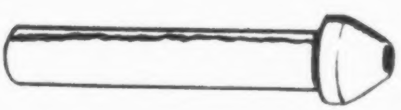
Connectors and couplings are used to connect thin-walled conduit to an outlet box.

INSULATORS



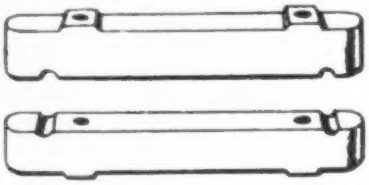
KNOBS

Porcelain knobs are used to support rubber-covered or weather-proof wire in knob-and-tube wiring systems.



TUBES

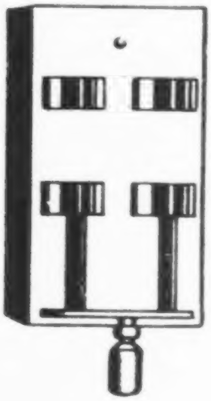
Porcelain tubes are used in knob-and-tube wiring to carry wire through walls and studs where one wire crosses over another.



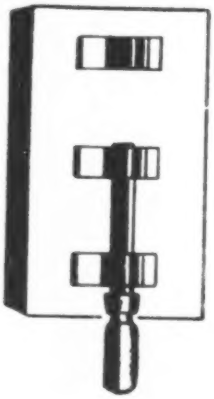
CLEATS

Cleats are used to support wires on walls in knob-and-tube systems.

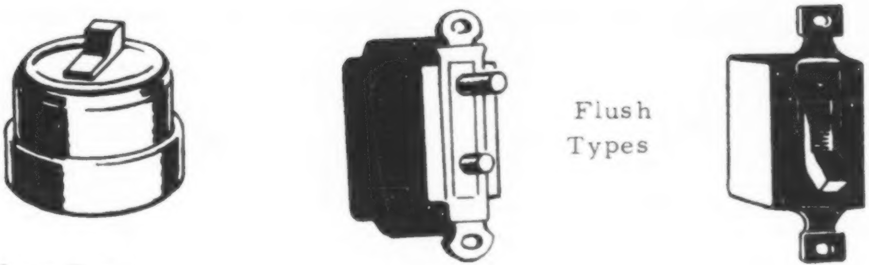
SWITCHES



KNIFE SWITCH



This type switch makes and breaks a circuit by moving the handle in and out of the switch clips.

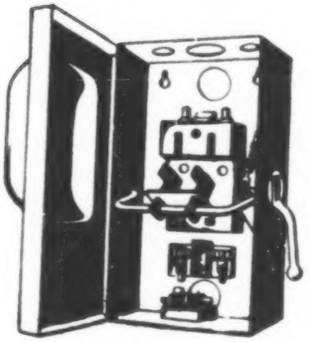


Surface Type

Flush Types

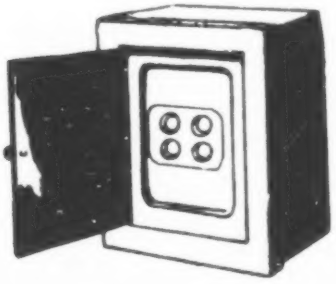
Toggle Switches

There are two types on toggle switches, flush or surface type. Flush type is compact and is mounted in a box in the wall. Surface type switches are mounted directly on the wall. Either type can be two-, three-, or four-way switches. Standard switches, cast-iron, waterproof, and explosion-proof switches, and sheet-metal dustproof switches are furnished.



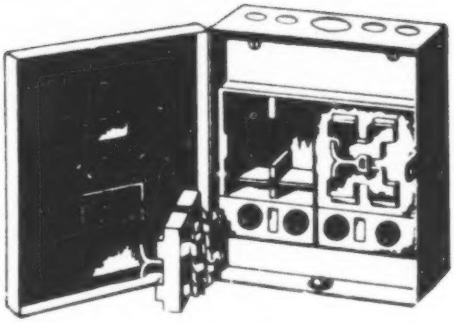
Service Switch Box

Small switch boxes are used in buildings for ordinary 30-ampere service. They are used to connect and disconnect wiring and power supply in a building. They are usually equipped with fuses to guard building circuits against short circuits and overheating.



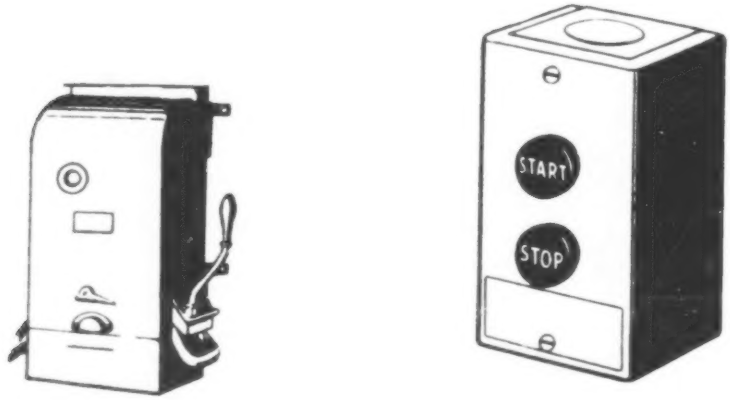
Fuse Box

A fuse box or panel is used to connect or disconnect building wiring to power supply through protecting fuses.



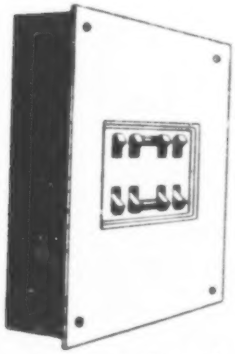
Combination fuse-and-switch boxes are used to control each circuit in a building separately. Six circuits can be controlled by this type of box.

Combination Box



Special-Type Switch

Special switches are used on motor installations to prevent overloading the wiring circuit. Large switches are lever-operated while small switches are push-button controlled.



Circuit-breakers are often used instead of fuses or switch boxes. When the amperage gets too high, the circuit-breaker switch automatically snaps off, opening the circuit. The thrown switch is easier to find than a blown fuse.

Circuit-Breakers

STUDY QUESTIONS:

1. What is the difference between a conducting and an insulating material?

2. What is the purpose of a fuse?

3. How does a time delay fuse operate?

4. What are several conducting materials?

NOTES:

1. CONDUCTORS
   - a. Definition
   - b. Principles of Operation

c. Common Conducting Materials

d. Measurement of Wire Conductors

e. Identified and Unidentified Conductors

f. Factors Affecting Resistance of a Conductor

2. INSULATORS

a. Definition

b. Purpose of Insulation

c. Types of Insulators

3. FUSES

a. Definition

b. Purpose

c. Principle of Operation

d. Types of Fuses

PART V - TYPES OF WIRING SYSTEMS

1. GENERAL

Nearly all current supplied by the power station is alternating current because its voltage can be stepped-up or stepped-down, by means of a simple and inexpensive transformer.

The reason for the advantage of being able to step-up or step-down voltage is that power companies are interested in the transmission of electric power and not voltage or amperage alone. Power is the rate of doing work. Electrical power is determined by multiplying the voltage by the rate of flow of current and is measured in watts.

Watts or Power = Volts x Amperes or $P = E \times I$

The power of 40 amperes passing through the circuit at 25 volts is the same as 20 amperes at 50 volts or 5 amperes at 200 volts.

$P = 20 \times 50 - 1{,}000$ watts

$P = 40 \times 25 - 1{,}000$ watts

$P = 5 \times 200 = 1{,}000$ watts

However, if the amperage is high the wires must be large to prevent their heating and thus causing heavy power loses. Therefore, if the voltage is kept high (voltage does not heat the wire) the current will be small thus the heating effect of the current will be small. This principle is used to send electrical power over long distances with little cost.

Alternatig current for power systems is almost always generated as three phase. That is, each generator is in effect three generators combined.

Figure Nr. 1 shows a graph of three phase current generation over a period of time. The solid line represents one phase. (This is all that would be seen under a single phase generation.)

When all three phases are considered, the end result is more power transmitted more economically.

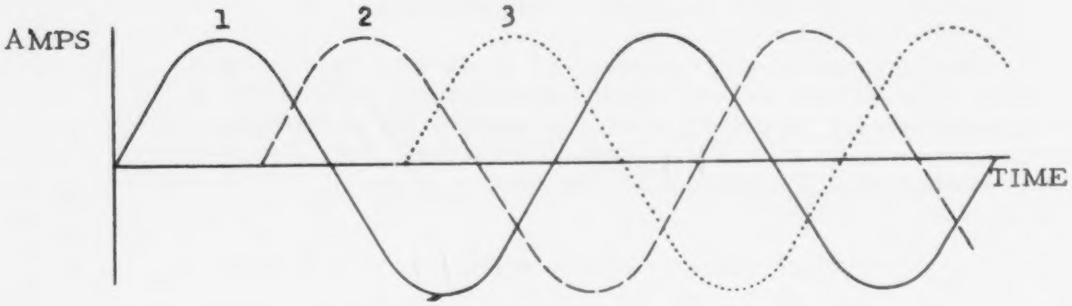


Figure Nr. 1 - Three Phase Current

2. POWER GENERATION

Electrical power has undergone many changes since it was first generated. At first, the only type power available to the consumer and to industry was single-phase two wire. This system proved to be inadequate as the demands for bigger, more complex machinery had to be met. Items were being produced on the market, such as washing machines, dryers, and other household goods, that called for a different type of current than was used for lighting and normal wall outlets. To compensate for this, new wiring systems were designed for power consumption that were capable of producing two different voltages.

a. Three Phase Power

Three phase power A.C. is three wire (deta system) or four wire, (wye system) depending on the type of system. It is possible to use three phase power to operate a big motor or heavy appliances while at the same time, operate a normal lighting and outlet circuit in the house.

b. Single Phase Lighting

At the same time we are using three-phase power, it is possible to branch off this circuit and derive single phase power, better known as 110 volt. This single phase circuit can be used for lighting systems and small electrical appliances which do not require three phases. Naturally, they would have to be re-designed for three-phase which would prove to be costly as well as impractical.

c. Use of Single-Phase In Operating Small Motors

Single phase 110 volt systems are normally used to operate small motors. Small motors do not necessarily need a high starting torque to perform their necessary functions, making the use of three-phase power, unnecessary.

3. SINGLE PHASE - TWO WIRE SYSTEM

There are two wires used in a single phase system; one hot lead and one "neutral", or return wire. This type system is always easily identified because there are only two wires utilized. This system is usually grounded to a pipe that is conveniently located, such as a water pipe. When reading voltage with a meter between the one "phase" or "hot" wire and a neutral, we should normally read 110 volts. (Providing system is in proper working order.) When reading from the hot wire to the ground, we should also get a 110 volt reading. Between the neutral and ground wire, the meter should read zero. By this method, we can determine which wire is hot, and which wire is neutral. It is necessary to know this because all switches, fuses, and controls must be placed in the lines ahead of the load, leaving the neutral only as a return. See Figure Nr. 2.

a. Voltage Is Normally 110

Single phase power is usually 110 volts alternating current. Normally when two wires are the only source of power, it can be assumed that this is single phase 110 V.A.C. The only deviation from this would be direct current wiring which could be carrying more or less than 110 volts in two wires.

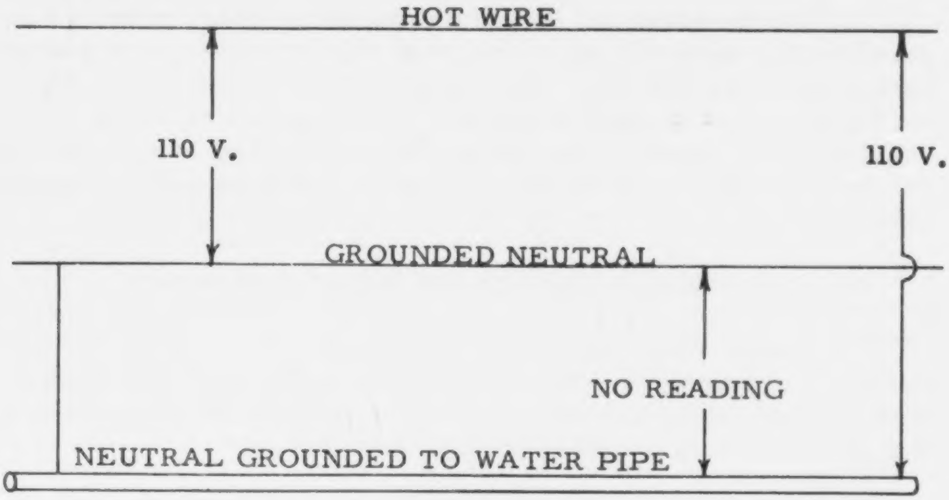


Figure Nr. 2 - Single Phase, Two-Wire System

b. Single Phase Used For Light Duty

Only small utilities such as motors for washing machines and household appliances can be used with single phase 110 volt systems because only a given amount of power can be derived from this type system. Anything used which requires power above 110 volts must go to a different type wiring system.

4. SINGLE PHASE - THREE-WIRE SYSTEM

The single phase - three wire system is named after the man who invented it, Thomas Edison. The Edison system can be used for either 110 volts or 220 volts and therefore, it is widely used in household applications where both voltages are required.

a. Three-Wire System (Edison)

The three wires utilized in the Edison system are one ground and two hot leads. By using different wiring arrangements, it is possible to obtain two different voltages. See the illustration below in Figure Nr. 3.

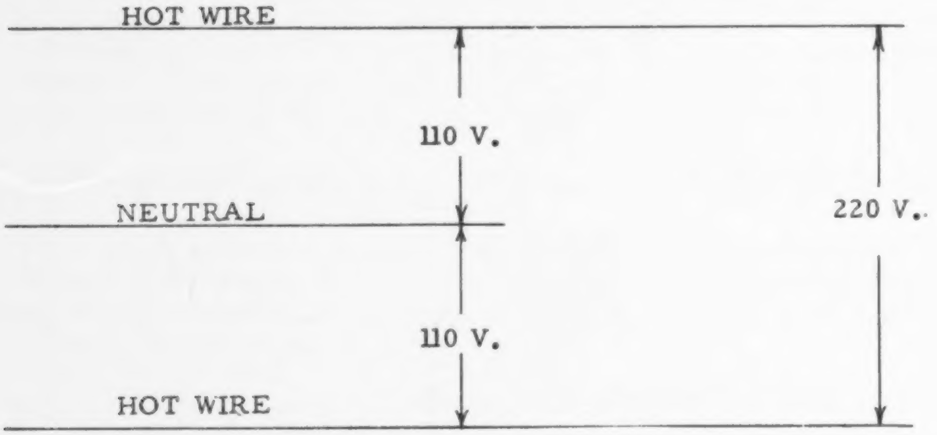


Figure Nr. 3 - Single Phase, Three-Wire System

b. Voltage Is Normally 110 or 220

The voltage across one hot lead and one ground is normally 110 volts. The voltage across two hot leads is 220 volts.

c. Purpose Of A Single-Phase, Three-Wire System

The Edison system can be used in houses where voltages higher than 110 volts are needed. Which means, any appliances requiring voltages higher than 110 volts can also utilize this system. This system may also be used for industrial applications, but normally this is not done to any great extent.

5. THREE PHASE - THREE-WIRE SYSTEM

This type of system is normally used in factories where power requirements are high. Because this is a high voltage system, it is not suited for use in the home as it cannot be used for certain appliances.

a. Three Hot Leads

There are three wires in this system and each wire is a "hot" wire or "phase" wire. By using this system, we actually can divide the load between all three phases allowing us to use lighter wires and smaller switches (current rating), giving us overall cheaper installation with a much higher efficiency. Below is an illustration showing the three phase, three-wire system. (Figure Nr. 4)

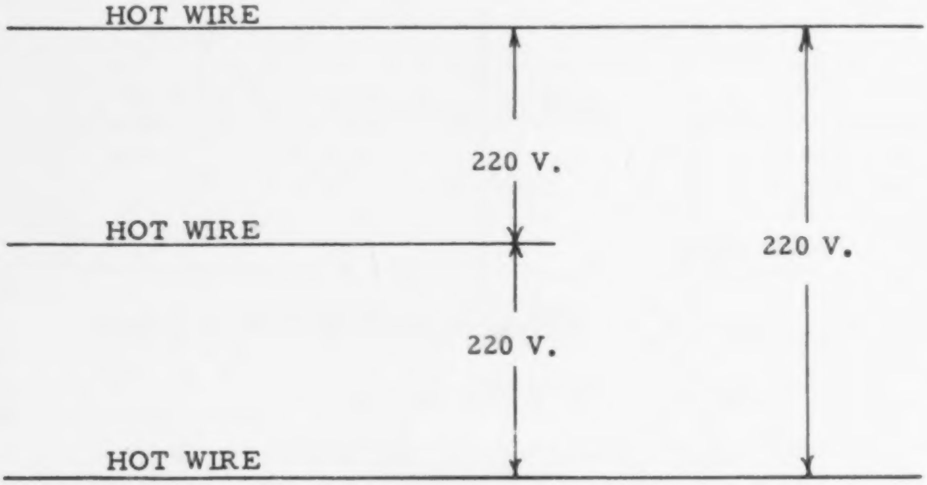


Figure Nr. 4 - Three Phase, Three-Wire System

b. Alternating Ground

Each lead in this type system is alternately a ground. That is, only two wires will be hot while the third is a ground. Since this is alternating current, there is a build-up of voltage in two of the lines, while the third line is acting as a ground. After the ground wire has reached its lowest voltage point, it then starts building up while the other wires (already having reached peak value, but at different times) are reducing in voltage. Thus, we have an alternating neutral.

c. Can Be Single Phase

The three-phase, three-wire system can be adapted to single phase use by taking one hot lead wire from the three-phase system and pairing this with an independent neutral or ground wire.

6. THREE PHASE - FOUR-WIRE SYSTEM

The three phase, four wire system is used frequently in industry and is an ideal system for running either 120 volt or 208 volt hook-ups as it is more adaptable than the previously mentioned systems. This system is different, in essence, from the three-phase, three-wire system because it has a positive ground wire.

a. Three Hot Leads

This system employes three hot leads, each having a voltage of 120 volts. 208 volts or 120 volts can be derived from this system depending upon the combination of wires used. AN example of this is shown below. (Figure Nr. 5)

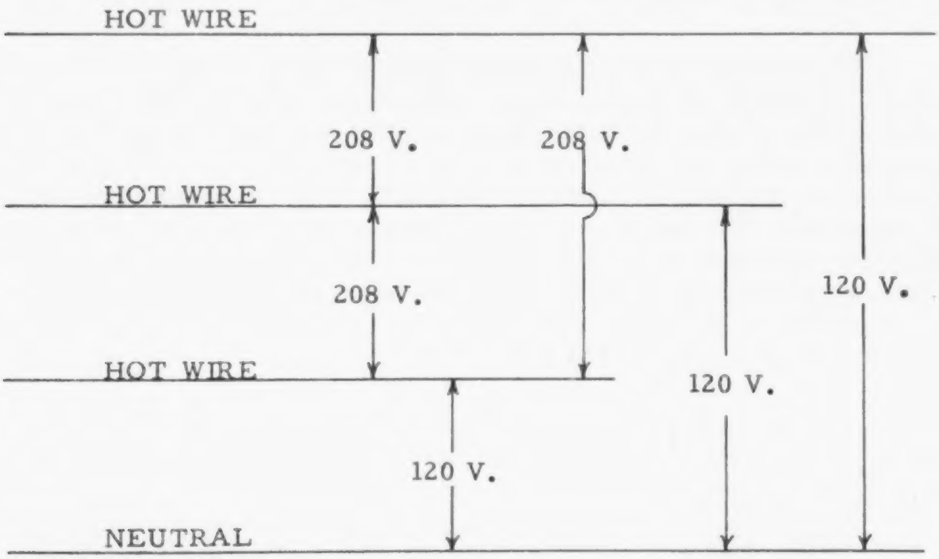


Figure Nr. 5 - Three-Phase, Four-Wire System

b. Voltage Is 120V or 208V

By connecting one end of all three coils together we can still obtain three phases or 208 volts. By connecting a neutral wire to the center connection of all three coils, we can obtain 110 volts or single phase.

c. Positive Ground Wire

This system differs from the three-phase, three-wire system in that it has a positive ground wire. This system is ideal for industrial purposes because it is so adaptable.

d. Purpose of a Thre-Phase, Four-Wire System

This system can be used in installations which require several lighting circuits and also one or more heavy motors. We can actually, by using pairs of phase wires and the neutral with each pair, obtain three Edison systems and still, by coming off with a parallel circuit, obtain power to run our three-phase motors, ignoring our neutral. This is the most efficient of the common wiring systems.

7. WIRING OF THREE-PHASE CIRCUITS

The National Electrical Code requires that in both three-phase systems, all three phases be broken. This greatly complicates the wiring system and as we lose simplicity, we also lose efficiency, and shorten the useful life of the controls that must be wired into each phase. Another problem to be considered is the power demand of the motor being wired. To determine the type of wiring system to be used, we must consider all factors pertaining to the efficient operation of what we are wiring.

a. Connection of Leads

The connection of the leads from our wiring system is important to assure efficient operation and the way they are connected varies with the type of wiring system.

(1) Delta

With the Delta system (three-phase, three-wire) there is no positive ground, so all leads are hooked directly to the load. Each wire at its peak is 220 volts. When using the Delta wiring system on a three-phase motor, at least two lines must be broken.

(2) "Y"

The "Y" or three-phase, four-wire system, as it is sometimes referred to, is hooked to the load with pairs of phase wires, ignoring the neutral which is hooked in such a manner as to provide a positive ground. Usually this type system is used in conjunction with lighting or other single phase wiring. With this type system, all three hot lines must be broken to gain any control over the system.

8. ARTIFICAL GROUNDS

In addition to equipment being grounded, it is also required that the building and equipment is housed in, be grounded for safety reasons.

a. No Natural Ground

If the building has not natural ground, it is necessary to provide an artifical ground. This ground must meet certain specifications before it can be accepted.

b. Material Used

The material used has to be of such a nature that it will conduct excessive electricity through it and into the earth where it will be harmless. A pipe 3/4" in diameter at least 10 feet in length is acceptable, of which at least 8 feet must be sunken into the earht.

c. Improper Grounding

The effects of too shallow a ground are that excessive electricity will not be carried into the ground to be rendered harmless, but will stay around the building and greatly enlarge the chances of fire or injury to personnel.

NOTES

1. THREE PHASE AND SINGLE PHASE GENERATION

2. SINGLE PHASE, TWO WIRE-SYSTEM

3. SINGLE PHASE, THREE WIRE-SYSTEM

4. THREE PHASE, THREE-WIRE

5. THREE PHASE, FOUR-WIRE

6. ARTIFICIAL GROUND

7. MISC NOTES

PART VI-ELECTRICAL CONTROL CIRCUITS

1. GENERAL

In larger refrigeration units, we shall find that larger electric motors are needed for more efficient operation of the equipment. You will also find that in a larger electric motor more power and current is required to operate it. However, we do not need this much current in our controls, consequently a lighter circuit is provided. This is called the control circuit.

2. SYMBOLS

As in any schematic of a circuit, we find that is is more convenient to use symbols when possible. Symbols are used just as we use abbreviations for words when we don't have the space to write out the entire word. Symbols are also used for neatness. In Figure 1, you will find some of the symbols used in control circuits.

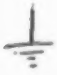
3. CONTROL CIRCUITS WITHOUT LINE STARTERS

a. Low voltage circuit. In lower voltage circuits, such as 110 volts, line starters are not always needed. This is accomplished by wiring the electrical motor in series with the control circuit. This circuit has contacts in it, which can either start or prevent the motor from being started. If any set of these contacts are broken the whole circuit is broken (Figure 2). These contacts should always be wired in the hot line, never across two lines. To do so would create a direct short in a two wire circuit. Because there is no voltage drop across a set of points, there is a voltage drop across a resistor such as a coil or a heater.

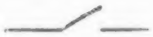
b. Control relays. Control relays may also be used to eliminate line starters. They are similar to line starters, but they break only one hot lead (Figure 3). Line starters break all of the leads to the motor. Usually a relay has only one set of contacts on a line starter.

In a three wire circuit (Figure 3), the control circuit is tapped off of one hot lead and the neutral. This provides a low 110 volts for the control circuit and allows us to use 220 volts for our electrical motor.

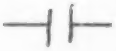
A. The ground for an electrical circuit is indicated in this manner:



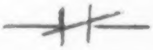
B. The switch in a control circuit is always drawn in the open position and is indicated like this:



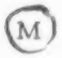
C. Normally open contacts are used to prevent certain parts of a circuit from being used until desired.



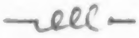
D. Normally closed contacts are used when power to something is desired instantaneously:



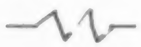
E. The electrical motor is indicated in this manner:



F. A coil, like for instance the one that closes or opens contacts, looks like this:



G. Resistance is always indicated like this:



H. The volts or voltage of a circuit is indicated by this symbol: V

I. The word phase has this symbol: ϕ

J. Contacts, such as push button switches, or reset buttons, are indicated by:

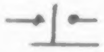


FIGURE 1 - Symbols for Control Circuits

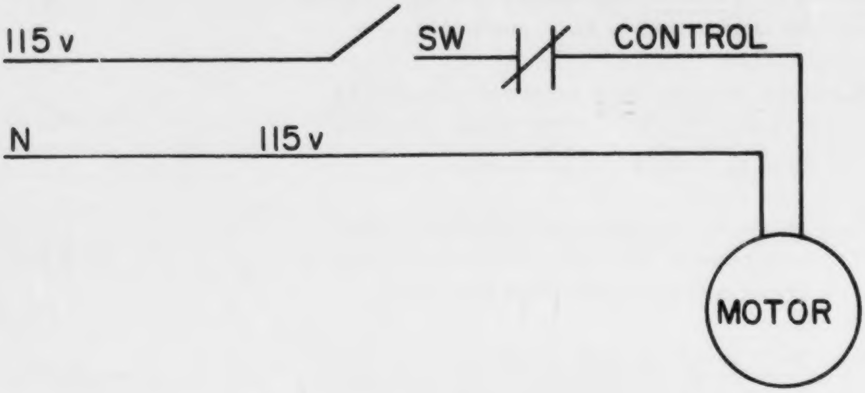

115 v
SW
CONTROL
N
115 v
MOTOR

FIGURE 2 - 115V, 1 Ø Control Circuit

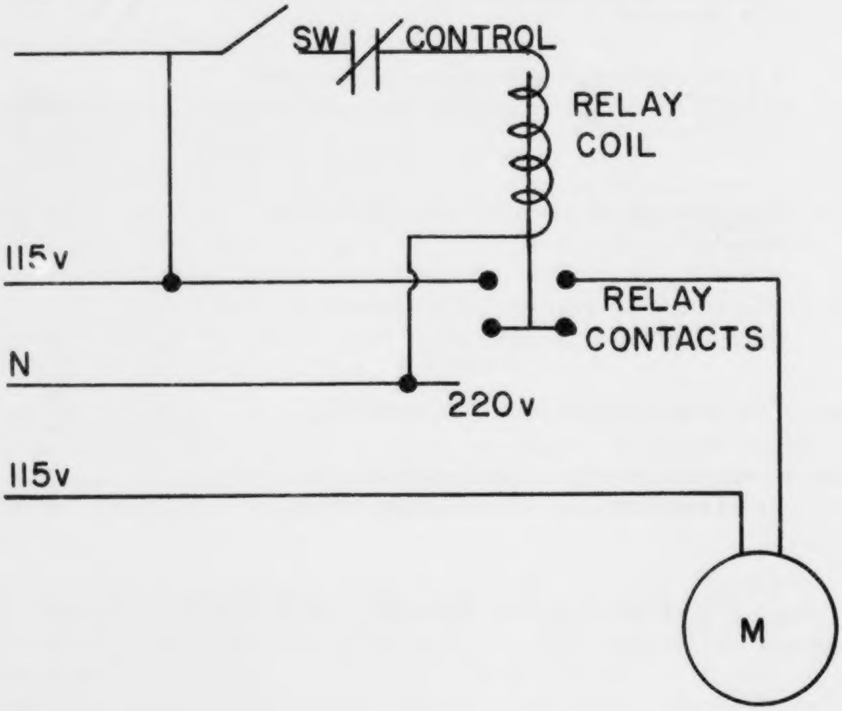

SW
CONTROL
RELAY COIL
115v
RELAY CONTACTS
N
220v
115v
M

FIGURE 3 - Three Wire 115 Volt Control

c. Control circuit. We can also use a 220 volt control circuit and a 220 volt motor (Figure 4). This is accomplished by tapping the control circuit off of two of the hot leads going to the motor.

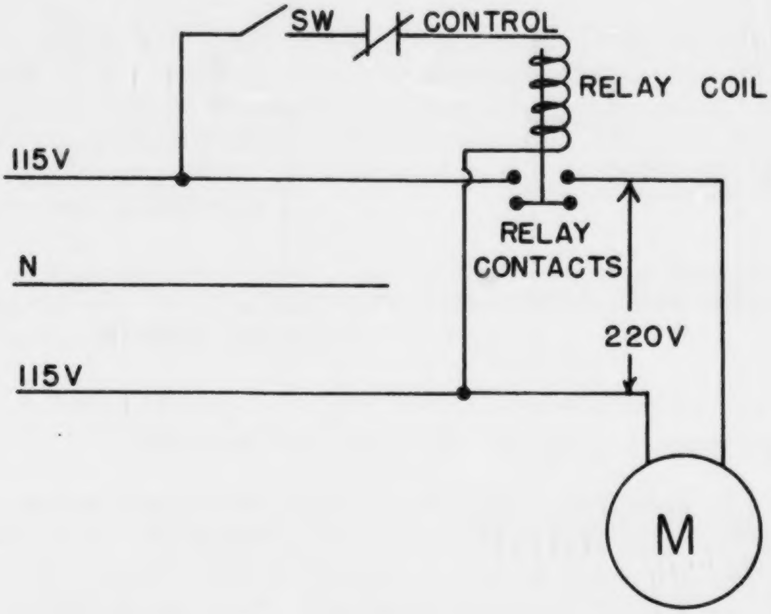


FIGURE 4 - Three Wire 220 Volt Control

d. Since relays are often used in these control circuits, we must provide some form of protection for them. This is done by using overloads. Overload relays are used on control circuits without line starters. They are similar to the soldered ratchet type thermal overload. Solder holds the ratchet in place (Figure 5). The heater is coiled around the solder. When excessive current is drawn through the heater, it melts the solder and the spring tension on the ratchet makes it trip opening the contacts and breaking the circuit. It then must be reset by pushing a button. The overload itself must be always located before the control and power circuit.

4. LINE STARTERS

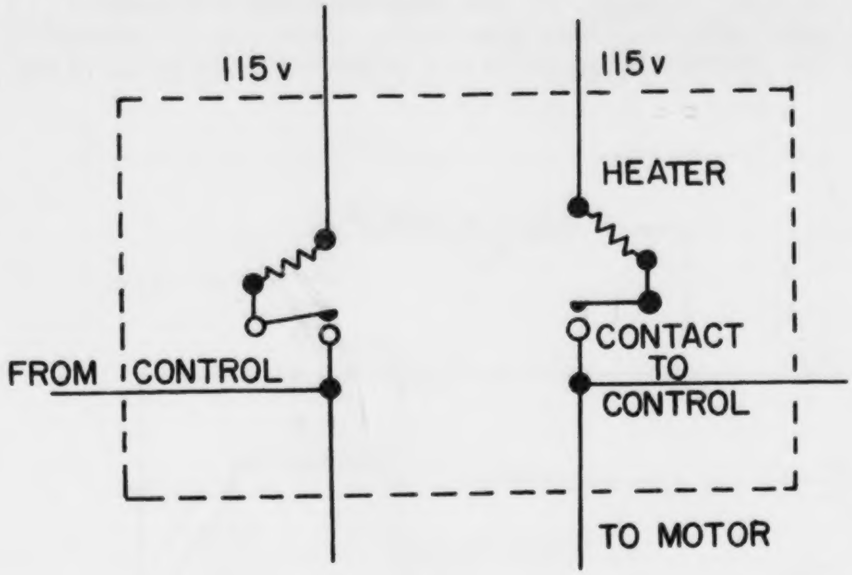


FIGURE 5 - Heater Elements for Overload

a. Use of control relays. Although control relays are practical, in most cases line starters are commonly used. Line starters provide many more conveniencies than relays. With line starters, we can get completely automatic control, using our standard controls to open or close the circuit to the electromagnet. We can also use two, three or four sets of contacts on a single insulating bar. Also auxiliary contacts can be used to energize other line starters and start other motors in a unit. A line starter electromagnet can be designed so that it is very strong. This means we can use very heavy contacts, and reduce the voltage drop across them to practically zero. This eliminates heating and gives a good clean switch. Also a line starter holding coil can be made to operate on much less voltage than the prime mover. This eliminates burning or pitting of contacts in controls throughout the control circuit.

b. Basic construction of line starters. Line starters made by different companies may look different but their basic construction is the same. They all consist of a housing, which houses all components, an electromagnetic coil, an armature, an insulator bar, springs, contacts, and some type of overload protectors. When the electromagnetic coil becomes energized, it acts on the armature, which inturn moves the insulator bar. The insulator bar contacts and completes the power circuit.

There are three types of contacts found in the line starter. The power side contacts, receives the incoming power. The load side contacts, have the motors or load attached to them. Both are heavely constructed. The auxiliary contacts, or spare contacts, are lightly constructed, and are used to supply power to other line starters and motors.

For overload protection, heaters are employed to open contacts upon excessive current draw. When these contacts open, current to the holding coil is stopped.

These heaters are used with bi-metallic strips or the solder ratchet type overloads.

The bi-metallic overloads or strips are made of two dissimilar metals permanently bonded together. When the bonded metals are heated, the metal on one side expands more than the metal on the other. This causes the metal to bend, opening the contacts. (Figure 6) The strip type overload is used in some line starters, although its action is slower than disc type used as motor protectors.

The soldered ratchet type overload is heated by the line or motor current. When the solder is heated, the ratchet wheel is then free to turn. This allows the relay to trip and open its contacts. After about two minutes, the solder solidifies and the overload can be reset by pressing the reset button.

5. CONTROLS

Also in the control circuit you will find other items such as controls, defrost timers, and relays.

a. Thermostatic motor control. The thermostatic motor control, controls cabinete temperature. It is actuated by a remote

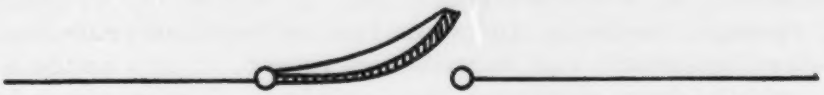


FIGURE 6 - Binetalic Strip

bulb in the cabinet. As the pressure in the bulb increases, it acts on a bellows which inturn either classes or opens a set of contacts. A rise in temperature will cause the bellows to expand and close contacts. This permits power to flow to the unit. A decrease in temperature causes the bellows to contract and open the contacts. This will stop the unit (Figure 7).

b. High pressure control. The high pressure control, acts as a safety device. When the pressure from the high side becomes too high, it also acts on a bellows, breaking the contacts to stop the unit. A decrease in pressure will cause the bellows to close the contacts.

c. Low pressure control. The low pressure control, is also a safety device. It acts as a temperature control and safety device on refrigeration equipment. Its principle of operation, however, is the same as the high pressure control. Each has a capillary line attached to either the suction or discharge side of the compressor. The presents or absence of pressure in this line cause the bellows to act on a set of contacts. These contacts are located in the control circuit.

When both the high pressure control and the low pressure control are united in a case, they are referred to as a dual pressure control.

d. Defrost timer. The automatic defrost timer, is used periodically to automatically defrost a unit. It runs when the switch is in the on position. Its actions are somewhat similar to that of a clock. It is set for the desired time you want the unit defrosted. The motor of the clock is wired in parallel from a power source.

The points can be wired in the control circuit and be used to energize a defrost solenoid valve. Some of these have auxiliary contacts to control other parts of a unit, such as relays, line starters, and pilot lights.

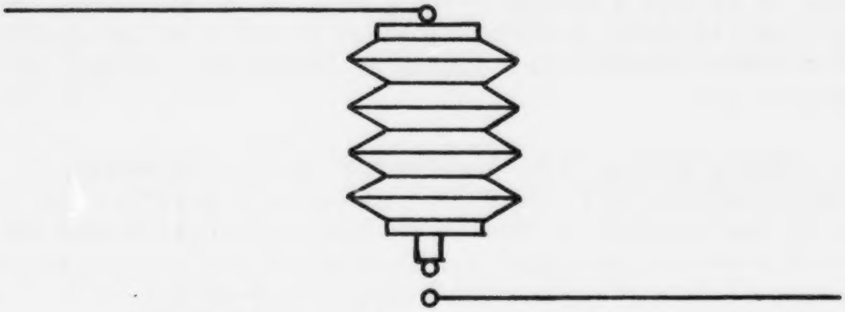


FIGURE 7 - Bellows Control

Relays may also be used on a unit to control various parts, by making and breaking the circuits. These relays are either normally opened or closed. These contacts may be either found in the power or control circuit.

Since the motors on these units are very expensive, we must also employ a safety device to prevent them from burning out. For this we use a bi-metallic disc type thermal overload. These overloads are set in the motor housing, this requires a special place for them. When the motor windings heat to a dangerous degree, these bi-metallic disc snap open very fast to break the control circuit.

In some cities and states, motors rated over a certain horsepower are required to have these overloads. This is due to the fire hazard they create.

6. CIRCUITS WITH LINE STARTERS

In circuits which contain line starters, all of the connections to the motor are broken instaneously by the line starter.

Line starters are used in circuits as a means for power control to the motors.

But before we can go into the operation of a line starter, we must first understand the different types of phases and wiring systems that can be used.

a. Wiring system. The simplest of all wiring systems is the single phase two-wire system. It consist of two wires, one hot and one common or neutral. It cannot be used to operate large motors. If we take a voltage reading between the two wires, we should read 110 volts between the phase or hot line, we should read 110 volts between the common or neutral and ground, we should read zero.

b. Single phase. The single phase three-wire system is commonly referred to as the Edison system. It uses two hot wires and one neutral. From this system we can get either 110 volts or 220 volts. With this type system, we can operate any unit that utilizes both 110 volt motors and a 220 volt motor.

c. Three phase. The three phase, three-wire wound system, is obtained by having three windings at 120° angles in our power supply. This results in what might be considered, three separate 220 volt single phase circuits without a neutral. We accomplish this by having the voltage on each pair (1-2, 2-3, 1-3) of wires at its peak at a different instant during the cycle, and using the extra wire as a neutral, thus we have an alternating neutral, but cannot get 110 volts from any part of this type system.

The fact that we have not one alternating 60-cycle current, but actually three, each reaching a peak of more than 220 volts with a constant flow makes this an ideal system for heavy motors with large current demands. By using this system, we actually can divide the load between all three phases, allowing us to use lighter wires and smaller switches (current rating), giving us an overall cheaper installation, but with a much higher efficiency.

d. Four-wire systems. The other three phase system is the four-wire system. By arranging our winding in our source still at 120° from one another, but connecting one end of all three coils together, we can still obtain three phases of hot wires, each pair giving us 208 volts, and at the same time, by connecting a neutral

Line starters are used in circuits as a means for power control to the motors.

But before we can go into the operation of a line starter, we must first understand the different types of phases and wiring systems that can be used.

a. Wiring system. The simplest of all wiring systems is the single phase two-wire system. It consist of two wires, one hot and one common or neutral. It cannot be used to operate large motors. If we take a voltage reading between the two wires, we should read 110 volts between the phase or hot line, we should read 110 volts between the common or neutral and ground, we should read zero.

b. Single phase. The single phase three-wire system is commonly referred to as the Edison system. It uses two hot wires and one neutral. From this system we can get either 110 volts or 220 volts. With this type system, we can operate any unit that utilizes both 110 volt motors and a 220 volt motor.

c. Three phase. The three phase, three-wire wound system, is obtained by having three windings at 120° angles in our power supply. This results in what might be considered, three separate 220 volt single phase circuits without a neutral. We accomplish this by having the voltage on each pair (1-2, 2-3, 1-3) of wires at its peak at a different instant during the cycle, and using the extra wire as a neutral, thus we have an alternating neutral, but cannot get 110 volts from any part of this type system.

The fact that we have not one alternating 60-cycle current, but actually three, each reaching a peak of more than 220 volts with a constant flow makes this an ideal system for heavy motors with large current demands. By using this system, we actually can divide the load between all three phases, allowing us to use lighter wires and smaller switches (current rating), giving us an overall cheaper installation, but with a much higher efficiency.

d. Four-wire systems. The other three phase system is the four-wire system. By arranging our winding in our source still at 120° from one another, but connecting one end of all three coils together, we can still obtain three phases of hot wires, each pair giving us 208 volts, and at the same time, by connecting a neutral

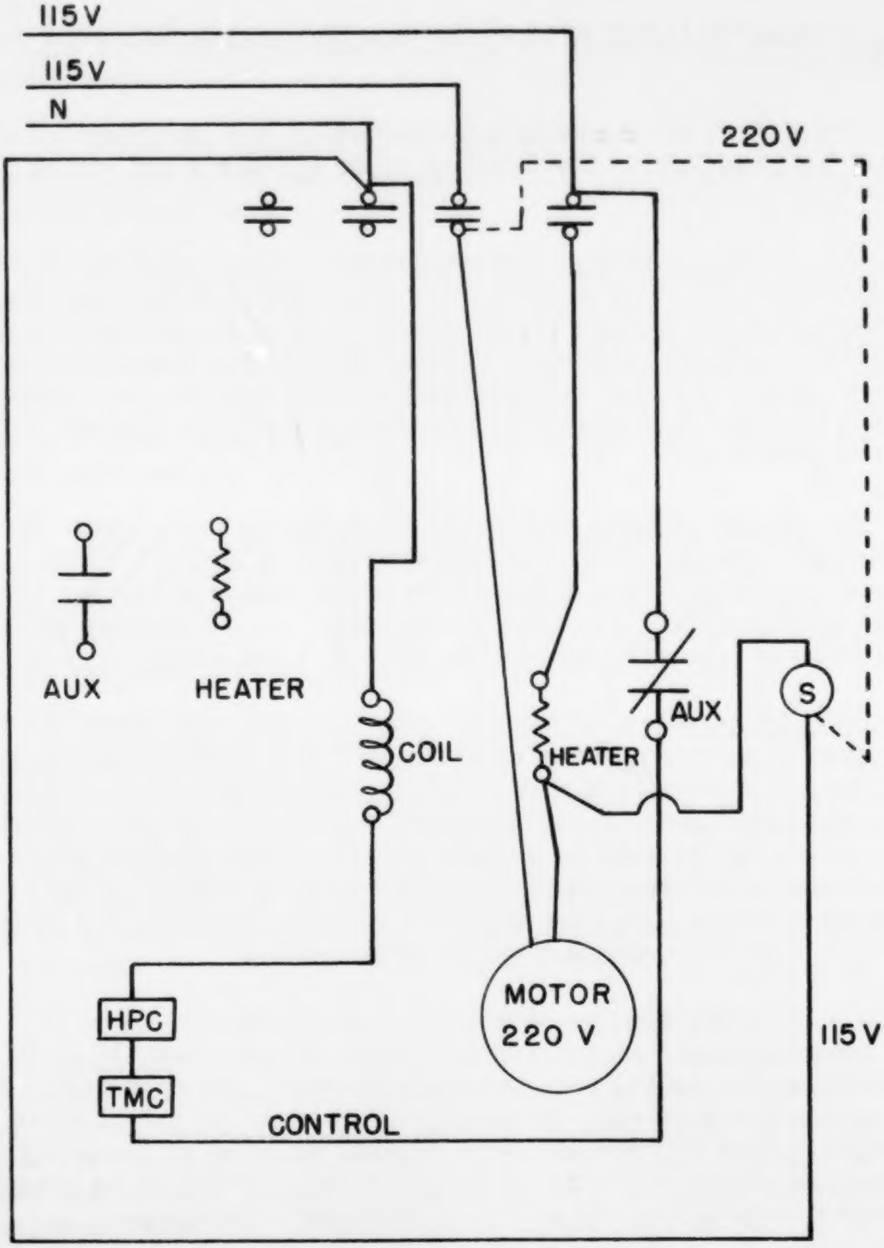

115V
115V
N
220V
AUX
HEATER
COIL
HEATER
AUX
S
MOTOR
220 V
HPC
TMC
CONTROL
115V

FIGURE 9 - Four Contact Line Starter 220V, 1 Ø Motor With A 115V Control Circuit, and 115V Liquid Line Solenoid. (May be wired for 220 volt operation.)

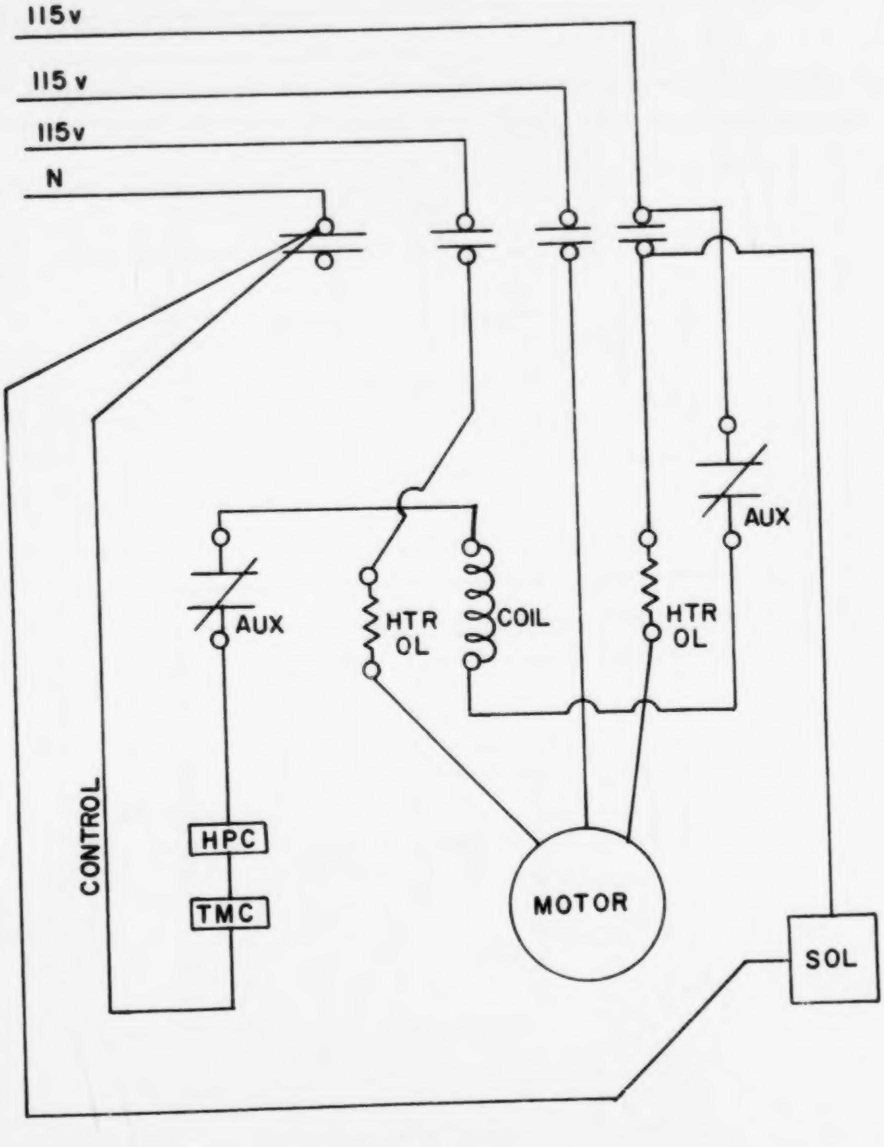

115v
115 v
115v
N
AUX
HTR
OL
COIL
HTR
OL
AUX
CONTROL
HPC
TMC
MOTOR
SOL

FIGURE 10 - Four Contact Line Starter With A 115V Control Circuit, A 220V, 3 Ø Motor and 115V Liquid Line Solenoid Valve.

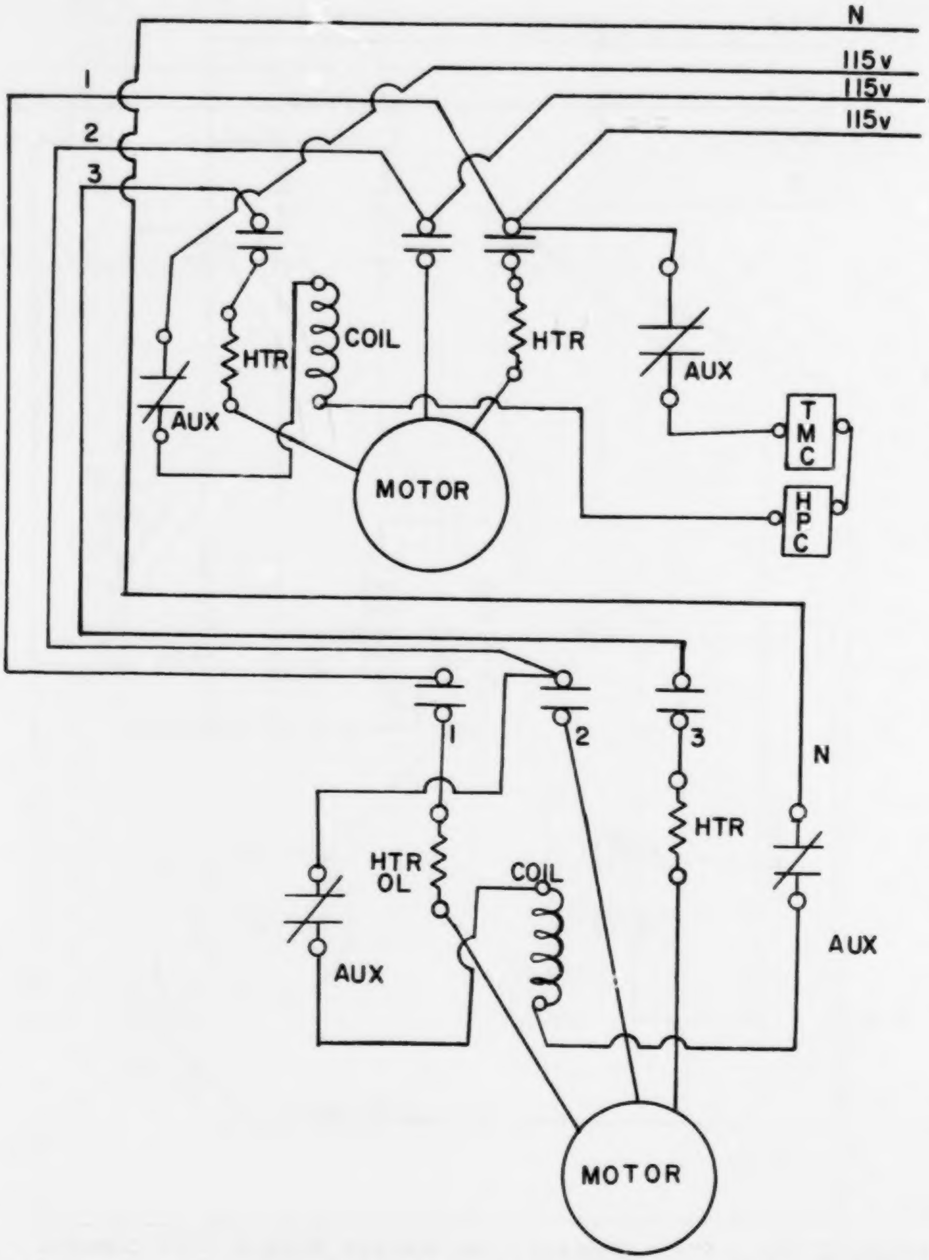

N
115v
115v
115v
1
2
3
HTR
COIL
HTR
AUX
AUX
T M C
H P C
MOTOR
1
2
3
N
HTR
HTR OL
COIL
AUX
AUX
MOTOR

FIGURE 11 - Four Contact Line Starter With A 220V Control Circuit to Start a 220V, 3 ∅ Compressor Motor. Auxiliary contacts used energizes a 220V line starter for a 220V, 3 ∅ water pump motor when compressor line starter closes.

7. JUNCTION BOXES

Junction boxes are used to provide a convenient means of connecting a number of wires together, such as on a motor.

STUDY QUESTIONS:

1. How are controls wired in the control circuit?

2. What is the function of the defrost timer?

3. How many wires are utilized in the Edison system?

4. What is the main purpose of the line starter?

5. Explain the operation of the bimetallic strip?

NOTES:

1. SYMBOLS

2. CONTROL CIRCUITS WITHOUT LINE STARTERS

3. LINE STARTERS

4. OVERLOADS

5. CONTROLS

a. **Thermostatic** motor control (TMC)

b. High Pressure control

c. Low pressure control

d. Dual pressure control

e. Automatic defrost timer

f. Motor overloads

6. CIRCUITS WITH LINE STARTERS

a. Single phase, two-wire system

b. Single phase, three-wire system

c. Three phase, three-wire system

d. Three-phase, four-wire system.

e. Four contact line starters used with 115V control circuit and 115V single phase motor.

f. 220V 1 ∅ motor with 115V control circuit and a 115V liquid line solenoid (or 220V solenoid).

g. 115V control circuit, 220V 3 Ø motor, and 115V solenoid valve.

h. 220V control circuit to a 220V 3 Ø comp. motor, auxiliary contacts energizes a 220V line starter for 220V 3 Ø water pump motor.

PART VII - MOTORS
SECTION I

Electrical energy may be converted into mechanical work by means of the electric motor. A simple DC motor consists of four main parts: (1) Two stationary electromagnets called field poles, (2) A rotating pole called an armature, (3) A commutator, which is a metal ring composed of two segments that are mounted on the axle of the motor and are insulated from each other, and (4) Two metal or carbon strips, called brushes, which are mounted in such a way that each is always in contact with one half of the commutator.

The direct current motor consists of two windings, the armature windings and the field windings. When the two windings are connected in series with each other the motor is known as a series wound motor (see Figure No. 5). This design gives the motor a very high starting torque but the speed varies considerably as the load changes. In fact, with no load, a series motor tends to run so fast that the commutator and winding are apt to be thrown off the armature by centrifugal force.

The main field winding can be connected directly across the power supply. (See Figure No. 6.) This is known as a shunt motor and the winding is called the shunt field. Such a motor has a rather constant speed with varying loads but tends to draw more starting current and have less starting torque (turning power) than the series motor.

It is most common in compressor drives, to use compound-wound motors. These contain both series and shunt fields. (See Figure No. 7.) The two field windings are wound on the same poles so that the field magnetism obtained is the sum of the effects of the two windings. As a result, the motor operation is a combination of some of the good characteristics from both types. Thus, constant speed medium starting torque are obtained in a motor to a marked degree.

1. POLYPHASE MOTORS

Alternating current motors of two or more phases are known as polyphase motors. These motors depend for their operation upon the principle of a rotating magnetic field. As a simple illustration of the principle of a rotating magnetic field, imagine a horseshoe magnet held over a compass needle. The needle will immediately take up a position parallel with the magnetic flux passing from one pole of the magnet to the other. If the magnet is rotated, the compass needle will follow:

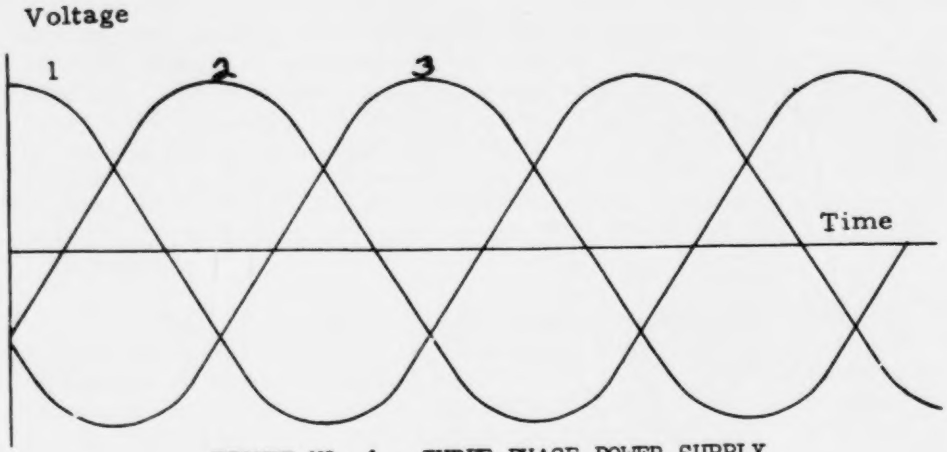


FIGURE NO. 1 - THREE PHASE POWER SUPPLY

A rotating magnetic field can be produced by a three phase current (shown in Figure No. 1) flowing through the coils of a three phase motor (shown in Figure No. 2 & 3).

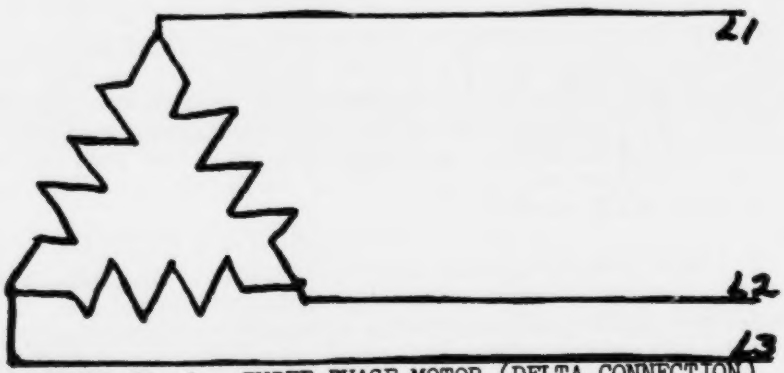


FIGURE NO. 2 - THREE PHASE MOTOR (DELTA CONNECTION)

The three phase power (Figure 1, 2, & 3) is such that current flows strongly in line 1 first, then in line 2, then line 3, and then in line 1 again. Thus coil 1 becomes magnetically strong first, then coil 2, then coil 3, then coil 1 again, and so on. The rotating field can be seen if a magnet, that is free to rotate is placed in the center of the stationary coils. The magnet will be

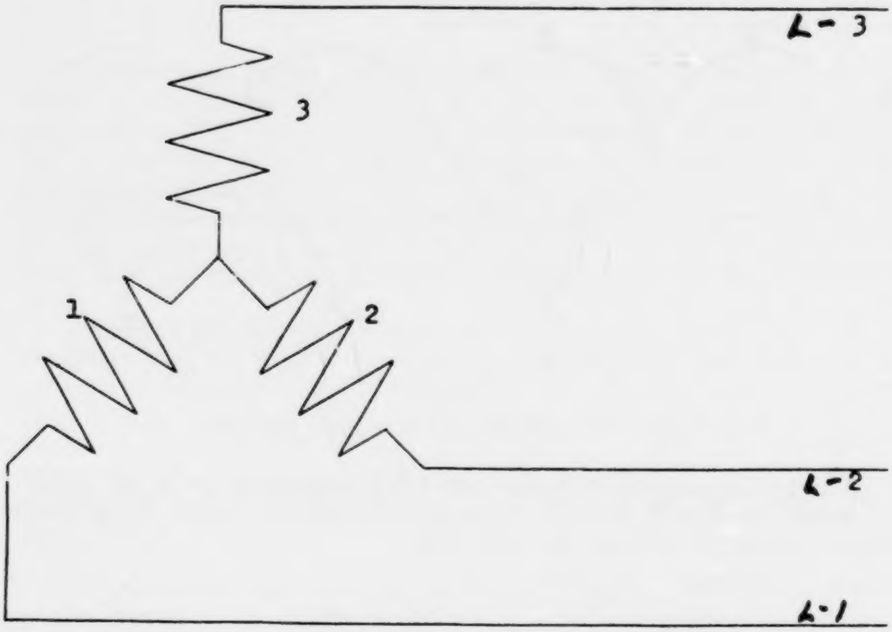


FIGURE NO. 3 - STATIONARY COILS ON THREE PHASE MOTOR

attracted to coil 1, when it is strong, then to coil 2, then to coil 3, then on to coil 1 again, and so on. This rotating field is the principle of operation of all polyphase motors.

2. SINGLE PHASE MOTORS

The most common type of electric motor is the single phase type which finds wide domestic and industrial applications. A few of the domestic appliances are vacuum cleaners, mixers, fans, and refrigerators. Although there are numerous variations of simple phase motors, there are five common types which you will see most often in your work. These are the shaded-pole, split-phase, capacitor-start induction run, capacitor start-capacitor run, and the permanent split capacitor motors.

The shaded-pole motor is used on equipment on which the starting loads are very light. Part of the field pole is surrounded by a heavy copper loop known as a shading ring. This ring has the characteristics of delaying the flow of magnetism through it which produces a weak rotating field and sets the rotor in motion if the load is not too heavy.

The split-phase motor is a constant speed single-phase motor and is used on equipment on which the starting load is light to medium. The motor has two windings in the stator, the run winding and start winding. The current through the run winding, owing to the coils of heavy wire, follows the current in the start winding, thus in effect producing two alternating currents in the motor. This is called splitting the phase and results in a rotating magnetic field which starts the rotor in motion. When the motor reaches approximately seventy-five percent of rated speed, the start winding is cutout by a switch.

The third type of single phase motor is the capacitor start induction run motor which is a constant speed motor used widely on equipment on which the starting load is heavy. The internal construction is similar to the split-phase motor with the exception of a capacitor placed in series with the start winding. This capacitor causes the current in the start winding to follow the current in the run winding by a wider margin then in the split-phase motor. This produces two alternating currents and a rotating magnetic field, the cutout switch serves the same purpose as before.

3. PERMANENT SPLIT CAPACITOR MOTOR

The permanent split capacitor motor is a constant speed motor used on equipment with a low to medium starting load. The construction is very similar to the capacitor-start motor with the exceptions of the type of capacitor used and the absence of a switch to cutout the start windings. With this variation the start windings and capacitor remain in the circuit as long as the motor is running. Its principle of operation is the same as the capacitor-start motor.

4. CAPACITOR START-CAPACITOR RUN MOTOR

The fifth type of single phase motor is the capacitor start-capacitor run motor which is a constant speed motor used widely on refrigeration equipment of 3/4 hp and larger. This motor is a combination of the capacitor start motor and the permanent split capacitor motor. It has a starting capacitor in series with the start winding and a cutout switch that opens at approximately seventy-five percent of rated speed. A running capacitor is wired in parallel with this switch and starting capacitor. The starting capacitor provides the motor with the ability to start under heavy loads and the run capacitor gives the motor the ability to operate continuously at high loads once it reaches full speed.

5. CUTOUT SWITCH

The cutout switch used on split phase, capacitor start, and the capacitor start-capacitor run motors may be of several types.

A centrifugal switch is used on open motors. This is the simplest type of cutout switch. Spring loaded weights are mounted on the rotor of the motor and move away from the shaft as the rotor reaches approximately seventy-five percent of rated speed. This mechanical movement is used to open a set of contacts and thus opens the circuit to the start windings.

This type of switch cannot be used on a hermetic unit. Instead a relay is used to open a contact. The different types of relays will be discussed in detail as you study hermetic units later in the course.

6. SMALL MOTOR SWITCHES (Figure #4)

This switch is used to protect against circuit overloads caused by fractional horsepower motors. It is installed the same as an ordinary switch using solderless connectors in the switch box.

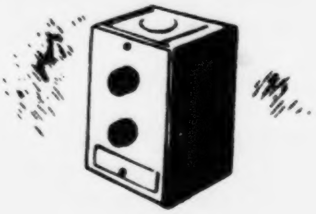


FIGURE NO. 4 - MOTOR-STARTING SWITCHES

7. LARGE MOTORS

Large squirrel-cage induction motors are started with special low voltage starter switches. The electrician connects the line wires to L1, L2, and L3 terminals, using the solderless connectors in the box. The starter switch is connected to the motor by wiring terminals T1, T2, and T3 on the switch box to corresponding terminals on the motor. These connections on the switch are made by using the solderless connectors in the starter box. Motor box terminals have solderless connectors in the motor box for wires at motor terminals T1, T2, and T3.

STUDY QUESTIONS:

1. What are the principle parts of a direct current motor?

2. What is the disadvantage of a shunt motor?

3. What is the most important characteristic of the series motor?

4. How do you reverse a direct current motor?

5. What is the principle of operation of a three phase motor?

6. What is the purpose of the centrifugal switch?

7. What does the capacitor accomplish during start-up of a capacitor-start motor?

8. List the types of single phase motors employed in refrigeration applications?

NOTES:

1. DC MOTORS

   a. Component Parts.

      (1) Field Poles:

      (2) Rotating Pole:

      (3) Commutator:

      (4) Brushes:

      (5) End Bells:

   b. Types & Characteristics.

      (1) Series wound motor.

(a) Speed:

(b) Starting Torque:

(c) Sizes:

(d) Reversal:

(e) Application:

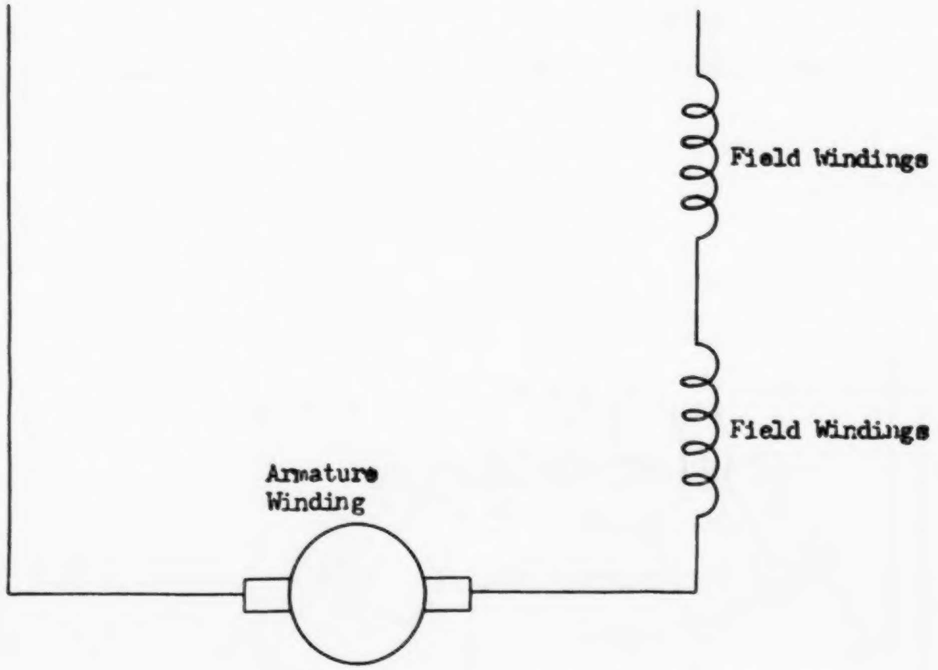

Field Windings
Field Windings
Armature Winding

FIGURE NO. 5 - SERIES WOUND MOTOR

(2) Shunt wound motor.

(a) Speed:

(b) Starting Torque:

(c) Sizes:

(d) Reversal:

(e) Application:

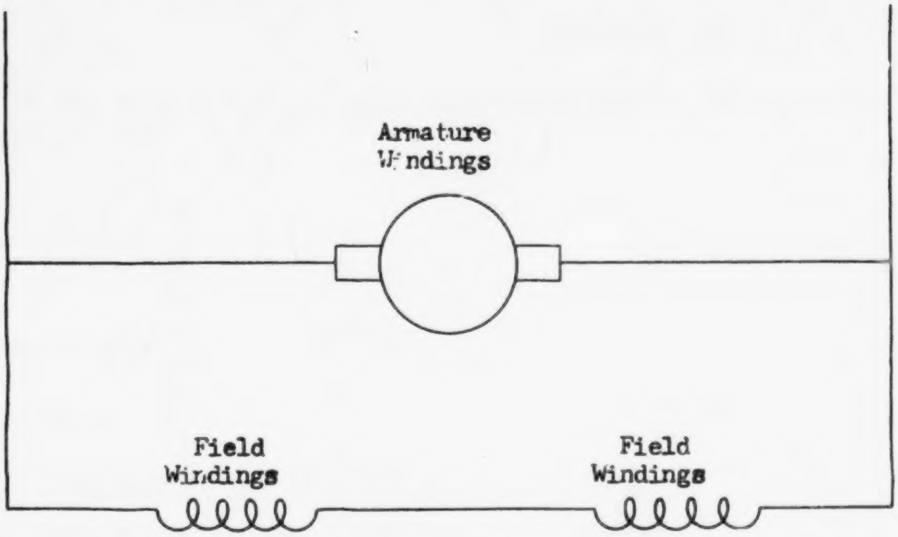

Armature Windings
Field Windings
Field Windings

FIGURE NO. 6 - SHUNT WOUND MOTOR

(3) Compound wound motor.

(a) Speed:

(b) Starting Torque:

(c) Sizes:

(d) Reversal:

(e) Application:

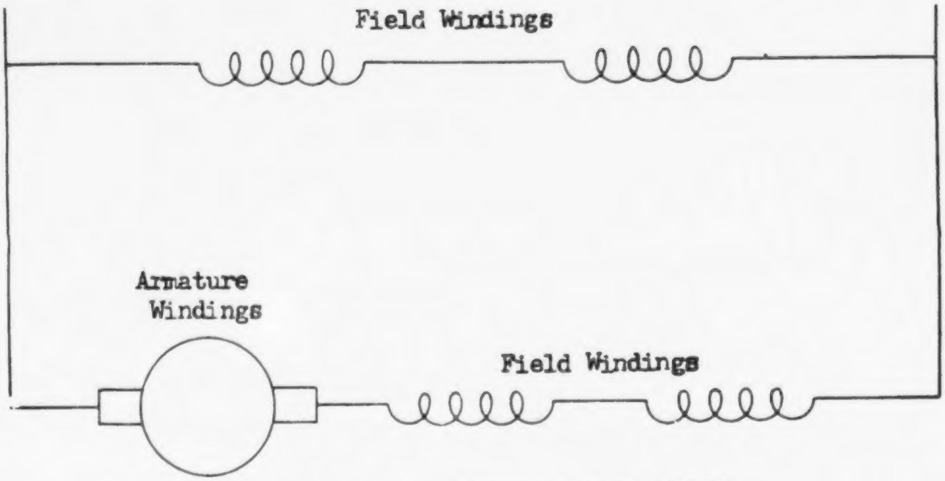
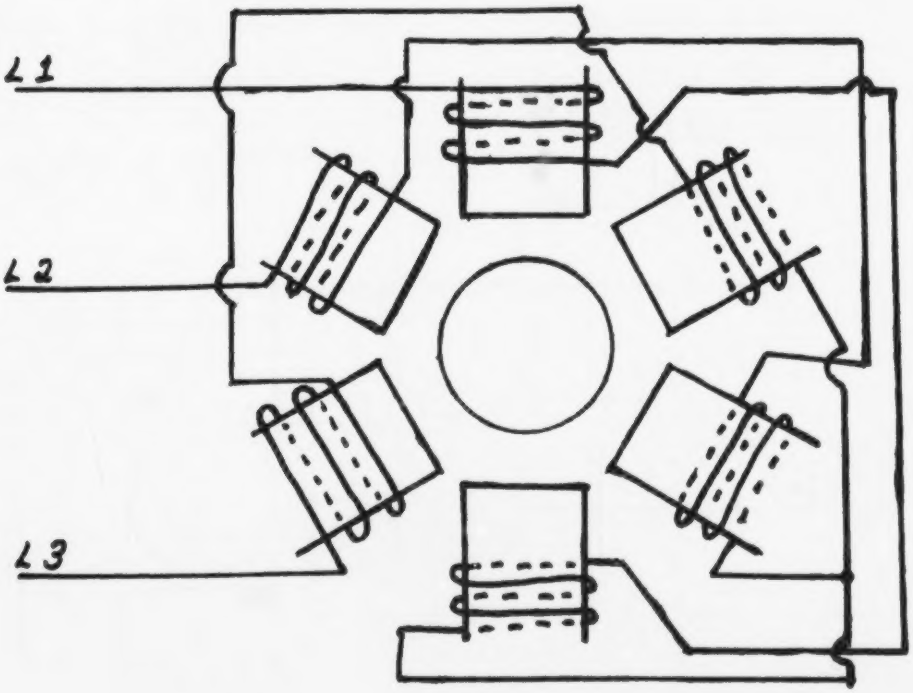

Field Windings
Armature Windings
Field Windings

FIGURE NO. 7 - COMPOUND WOUND MOTOR

2. POLYPHASE MOTORS (3 PHASE WYE SHOWN)



a. Component Parts.

(1)

(2)

(3)

(4)

b. Principles of Operation:

c. Characteristics.

(1) Speed:

(2) Starting Torque:

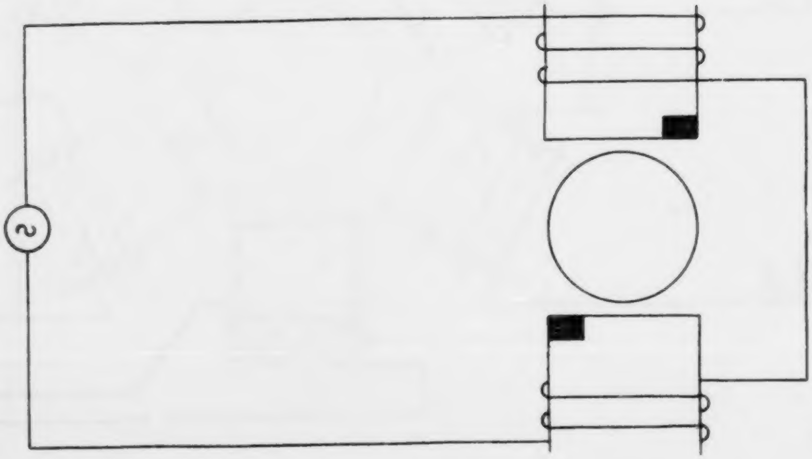
(3) Sizes:

(4) Reversal:

(5) Application:

3. SINGLE PHASE MOTORS

a. Shaded Pole Motor.



(1) Component parts.

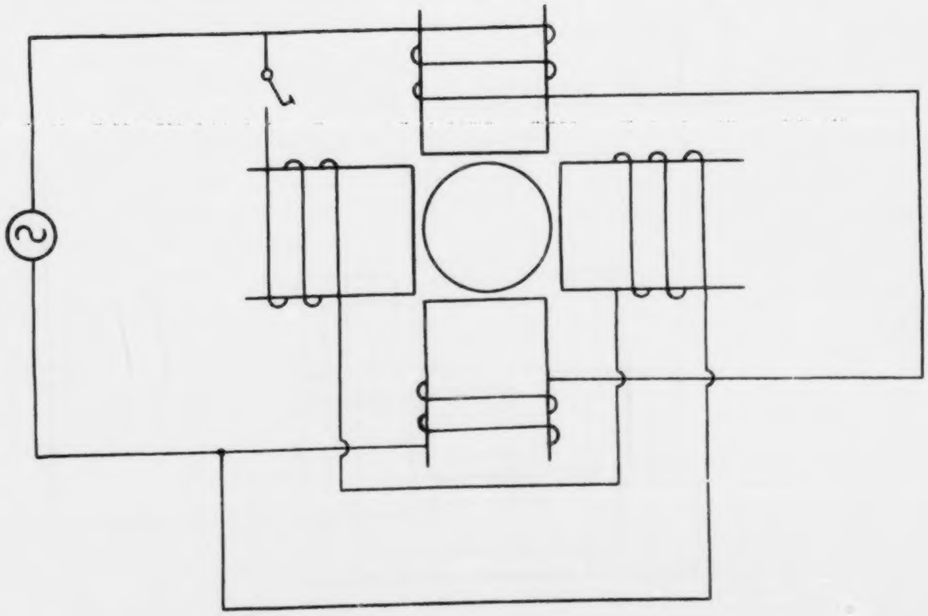
- (a) Frame
- (b) Stator
- (c) Squirrel Cage Rotor
- (d) End Bells
- (e)

(2) Principle of Operation:

(3) Characteristics.

- (1) Speed:
- (2) Starting Torque:
- (3) Sizes:
- (4) Reversal:
- (5) Application:

b. Split-Phase Motor.



(1) Component parts.

(a) Frame

(b) Stator

(c) Squirrel Cage Rotor

(d) End Bells

(e)

(2) Principle of operation:

(3) Characteristics.

(1) Speed:

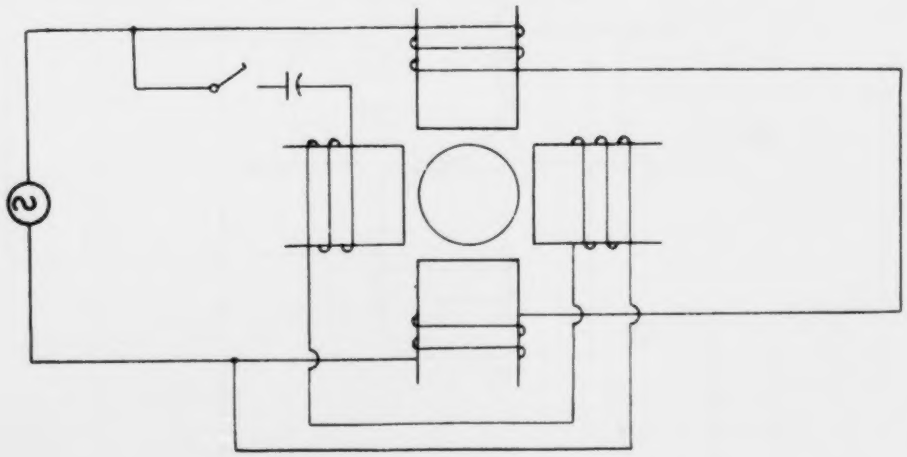
(b) Starting Torque:

(c) Size

(d) Reversal:

(e) Application:

c. Capacitor Start Induction Run Motor.



(1) Component Parts.

(a) Frame

(b) Stator

(c) Squirrel Cage Rotor

(d) End Bells

(e) Cutout Switch

(f)

(2) Principle of Operation:

(3) Characteristics.

(a) Speed:

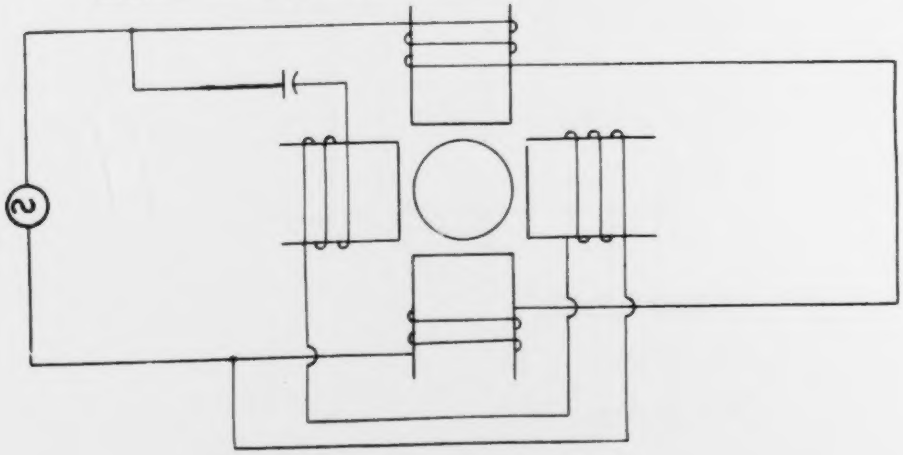
(b) Starting Torque:

(c) Size:

(d) Reversal:

(e) Applications:

d. Permanent Split Capacitor Motor.



(1) Component Parts.

(2) Principle of Operation:

(3) Characteristics.

(a) Speed:

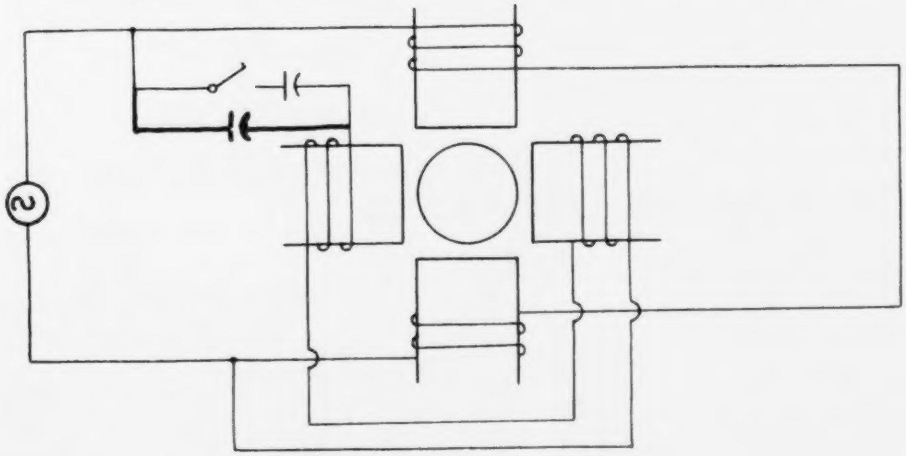
(b) Starting Torque:

(c) Size:

(d) Reversal:

(e) Application:

e. Capacitor Start - Capacitor Run Motor.



(1) Component Parts.

(a) Frame

(b) Stator

(c) Squirrel Cage Rotor

(d) End Bells

(e) Cutout Switch

(f)

(g)

(2) Principle of Operation:

(3) Characteristics:

(a) Speed:

(b) Starting Torque:

(c) Sizes:

(d) Reversal:

(e) Application:

f. Cutout Switches.

(1)

(2)

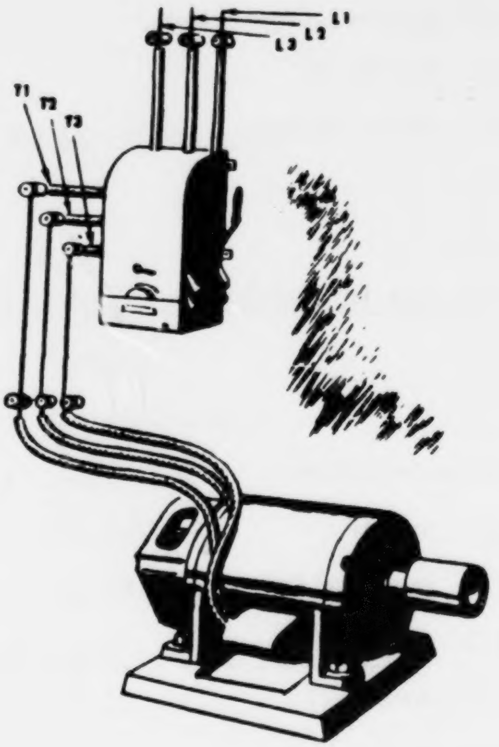


FIGURE NO. 8 - LARGE MOTOR - METHOD OF CONNECTING

TIPS AND TECHNIQUES:

1. MOTOR CHARACTERISTICS

a. Rating. Motors are rated by horsepower, speed and temperature. The name plate on the motor gives this information as well as the operating voltages and currents and a wire-connection diagram. (Figure No. 8.)

b. Horsepower. The rated horsepower is the amount of power the motor can deliver continuously without damage to itself. For short periods, the motor can deliver more than its rated horsepower.

c. Speed. The speed is rated in revolutions per minute (rpm) while the motor is running at full load. Some motors are constant speed under load; other motors decrease speed as load is applied.

d. Temperature. Motors are rated on the temperature rise permitted above room temperature. The rated temperature is usually 72°F. For example, the temperature of a motor running in a room with a temperature of 100°F. will be 172°F. The motor will be too hot to touch, but the running temperature of the motor will still be safe.

2. MOTOR CARE AND MAINTENANCE

a. Dust. Fine particles of sand and dust settling on the moving parts of the motor scratch and groove bearing surfaces. Accumulated dust picks up oil forming a gummy mask that reduces the lubrication value of the oil and plugs ventilation spaces.

Periodically, dust must be wiped off the motor and its moving parts. Dust can be blown out of the windings with compressed air at fairly low pressure (not over 40 PSI).

b. Oil. Oil lubricates and protects moving parts of the motor. Oil must be kept in the bearings.

Excess oil attacks the insulating material on wires and combines with dust to form a sticky gum that slows down the motor and causes sparking and shorting.

c. Removing oil and dust. Oil and dust must be wiped off periodically and the motor should be cleaned with a non-inflammable solvent. The motor should be allowed to dry after oil and dirt are removed and the windings painted with insulating varnish.

d. Moisture. Moisture should be kept away from motors as much as possible. Moisture has two effects on motors. These effects are: (1) Soaked insulation is noninsulating, causing shorts in the motor and (2) A combination of water and other elements rots insulating material and causes rust and corrosion.

Motors should be covered or kept in a dry place. Moisture should be wiped off and the motor dried in an oven or other heat source and by circulating air through the motor with a fan.

e. Mounting. Improperly mounted motors will vibrate, shortening the life of the motor. It is often the electrician's job to mount the motor and check it in maintenance work. Just as rutting is fought in road maintenance, grooving should be fought in motor maintenance.

f. Wear. Dirt and grit collecting on the commutator cause it to wear unevenly and produce faulty motor operation. A grooved commutator can be smoothed by running the motor at normal speed and holding 00 sandpaper against the commutator.

g. Undercutting mica. To stop excessive brush wear or sparking, the mica separating the commutator bars must be undercut about 1/32 of an inch. To undercut mica, grind a hacksaw blade to the thickness of the mica joint. Saw in the mica groove until the mica is cut approximately 1/32 of an inch below the surface of the commutator bar.

h. Emery cloth must never be used. The fine particles on the cloth are conductors and will short the motor.

i. Overload. Motors should never be required to pull a load higher than the rated capacity except for very short periods.

Overloading heats the motor up and melts soldered joints or burns up insulation.

MOTORS
SECTION II

While an electric motor is one of the most efficient machines known today, and will operate with a minimum of attention, systematic care means not only fewer motor failures, but also lower repair costs.

Too often, however, maintenance is considered a kind of handyman's job that almost anyone can do without previous experience or training. This erroneous conception has, in many cases, led to expensive production halts, high repair costs, unnecessary motor replacements and employee injuries due to broken shafts, poor working tools--all of which can be prevented.

The purpose of this booklet is to catalog the more common electric motor troubles and corresponding maintenance procedures.

1. DUST

a. General

A handful of sand slipped into a bearing--and an electric motor vital to production would grind to a halt. Of course, no one would deliberately sabotage a motor in this manner--but we do have to contend with the greatest saboteur of all times Mother Nature Herself. Instead of sand, her weapon is dust...fine pulverized sand, perhaps, or tiny particles of any number of substances. Instead of swift action, her sabotage is slow.

Every minute of every day, dust is settling on motors--on housings, on windings, on slip rings and commutators--trying to work its way into bearings. (Naturally, this danger is at a minimum in the case of totally enclosed, fan-cooled motors.)

On windings, dust acts as a layer of insulation--confining heat until it may reach dangerous temperatures. Dust also plugs ventilation spaces--further interfering with proper cooling.

On slip rings and commutators, dust acts both as an abrasive and as an insulator--multiplying wear and blocking full passage of current.

Once inside bearings, dust can be as harmful as sandpaper to the highly polished surfaces.

But dust holds an even more serious threat to the life of an electric motor. If allowed to fill up the open spades in windings, it turns the whole wound section into a sponge for soaking up harmful oil, moisture, acid fumes, etc.

b. How to Fight Dust

The time to catch dust in motors is before it has had a chance to unite with water or oil to form a gummy mess. That means wiping off the motors on regular inspections--their housings, slip rings, commutators --and occasionally blowing dust out of the wound section with fairly low pressure (not over 40 lbs. pressure) compressed air. (If no compressor is available, a hand bellows can be used.)

The compressed air must not contain grit, metal or moisture. And if there is danger that blowing may shoot abrasive or conductive material into the air gap or windings, suction may be the preferable method of cleaning.

To keep dust out of bearings, see that oil filler caps are always closed ... and that dust seals and gaskets are in good condition. If they are worn or rotten--as they may become in time--remember that seals are much easier to replace than burned out bearings.

Above all, remember that dust is a relentless enemy ... requiring a continuous, wide-awake defense by maintenance.

Mother Nature, master saboteur, never sleeps!

2. STRAY OIL

a. General

Because it fights friction, oil is often called the "lifeblood" of motors. And inside bearings, that's exactly what it is. But outside the bearings, oil is strictly poison to electric motors.

When dust was discussed on the previous pages, its ability to soak up stray oil was noted.

And this trouble-making teamwork operates the other way, too. Sticky oil catches dust ... just as flypaper catches flies.

When both oil and dirt cover a commutator, good commutation is impossible to obtain. The faces of brushes become glazed and packed with dirt. Harmful sparking is sure to result.

Oil also harms commutators by deteriorating the mica insulating segments between bars.

To insulation on windings, oil is even more harmful. Once a winding is thoroughly oil-soaked, the motor is in immedate danger of a burn-out or breakdown. The soaked winding will probably have to be rewound.

But oil is most dangerous to a motor when it has had a change to unite with dust in the windings ... to produce a greasy, gummy mess. Then ventilation is smothered; windings are under continuous attack from oil; any metallic dust present is caught and held in this "gum"--a constant threat of shorting or grounding.

b. How to Fight Stray Oil

When oil and dust have been allowed to build up, the heavy mess should be removed with the aid of a solvent--preferably a non-toxic and non-inflammable one. If brushes or scrapers or used, be careful not to scrape the insulation!

Use solvents with caution, too, taking care not to soak the insulation--on which the solvent is apt to have a softening effect. When all the oil and dirt are out, dry the windings and apply insulating varnish.

In many plants, it may be impossible to keep a certain amount of cutting oil and other oils from reaching a motor in the form of a mist. (But that which lands on the outside should be wiped off before it can travel inside!)

On the other hand, much can be accomplished in fighting stray oil by keeping a motor's own lubricating oil where it belongs!

For example, never lubricate sleeve bearings equipped with oil rings when the motor is running. The oil level then does not indicate full supply. A certain amount of oil is riding the ring above the level ... and overfilling and escape of oil are apt to result.

And check oil seals, well covers and plugs at regular intervals to see that they are tight. Once outside a bearing, oil means trouble!

3. MOISTURE

a. General

Heaven for a motor most certainly would be a dry place. And while it is impractical to keep motors completely dry in many installations, that nevertheless should be one general aim of effective maintenance.

Failing in that, the second aim should be to get rid of moisture lodged in a motor as quickly as possible--for two reasons.

First, it takes time for moisture to soak and soften insulation. Often, it is possible to get it out before the damage is done.

Second, evaporated moisture is pure water when it first condenses in a motor. It is then at its least dangerous stage. But every extra hour water stays in a motor gives it just that much more time to absorb harmful compounds and become an active, destructive agent.

b. How to Fight Moisture

Every effort should be made to keep water in liquid form from dripping on, splashing on, or flooding a motor ... unless, of course, the motor is of splash-proof design.

Whether air-borne moisture has produced a harmful condition in the motor can be determined by testing insulation resistance. When resistance has dropped to a dangerous point, the motor should be dried out by one of these methods:

(1) Where an oven is available, this is the best method of drying.

(2) Circulate current through the windings to produce heat inside the insulation--driving moisture outward. Lock the armature to prevent rotation and use a rheostat to apply low-voltage current.

(3) Use a fan to force air through hot elements (resistors, steam pipes, etc.) and into windings.

(4) Enclose the motor with non-inflammable materials and convey heat to it through ducts.

(5) Cover the motor with a tarpaulin--leaving openings at top and bottom for air circulation--and provide heat with one or more electric light bulbs.

Whatever method is used, care should be taken that the drying is accomplished without damage to the insulation. Better interrupt the baking for a resistance test than bake insulation to the point of brittleness or burning. (The baking temperature should not greatly exceed the boiling point of water.) When dry, renew your motor's resistance to moisture by applying a good grade of insulating varnish.

For continuous uninterrupted service it is essential to keep motors dry by preventing or removing accumulated moisture.

4. FRICTION

a. General

In theory, no wear can take place within a bearing if the surfaces are smooth and properly lubricated. A film of oil then keeps them apart--prevents metal-to-metal contact and scraping ... just as truck wheels separate and prevent scraping between a box being moved and the floor under it.

But in actual practice, bearings often receive an insufficient supply of oil--or the wrong oil--or grit gets into the oil and produces scraping--or so much load is put on the bearing that the film of oil breaks down.

Preventing these conditions--as far as possible--is one of the main jobs of motor maintenance.

b. How to Fight Fricition

Rule number one in fighting friction is to pay close attention to the motor manufacturer's lubrication instructions ... specifying type and grade of lubricant, frequency of lubrication, etc.

Don't under any circumstances try to guess what grade and type of oil to use. Oil is the lowest item of operating cost--yet no one thing is more sure to cause trouble and expense than incorrect lubrication. Use only oil of the best quality and the correct grade suited to the requirements of each individual motor. If in doubt, write the manufacturer--he will be pleased to send proper lubrication instructions.

And with sleeve bearings, it is important to see that the oil ring is free and is turning with the shaft. At regular intervals, the oil reservoir should be flushed out and refilled--and the dust seals checked.

Where the anti-friction type of bearing is used--ball or roller--keep in mind that the main purpose of grease is to guard the steel rolling elements and races from corrosion, not friction. Too much grease only promotes friction and heat!

And remember that in any type of bearing the effective film of lubricant is often microscopically thin. Excess load can break it down--resulting in metal-to-metal scraping and bearing failure ... all in a matter of seconds!

Thus, needless extra tension in belt and chain drives should be avoided. And--similarly--proper alignment should be maintained between motor, drive and machine--as discussed on the next page.

5. MISALIGNMENT

a. General

Sprung or broken shafts, burned-out bearings, overload failure--are examples of motor damage commonly caused by misalignment. And the damage can occur in drive or driven machine, too. For when these elements are assembled in incorrect geometry, bending, breaking or excessive wear must result. Something has to "give"!

Nor does the trouble necessarily go back to improper original installation of equipment. Settlement of foundations, heavy floor loading, excessive bearing wear--these and other factors can throw alignment out of kilter.

The fact that motor and machine may be mounted on a common, rigid base is no proof against misalignment. The base itself may have been mounted off-level ... leading to a warp in its structure.

And if spur gears are employed in the drive, the tendency of these gears to push apart often can disturb alignment in time.

Obviously, alignment must be maintained if motors are to be maintained!

b. How to Fight Misalignment

Misalignment sometimes gives you a warning. Excessive temperature may warn that it is causing bearing overload or motor overload. Increased vibration may be the warning signal. Or you may hear a rapid knocking--a sign that a shoulder of the shaft is being driven against the end of a bearing.

If the installation is not too heavy, it may be possible to lossen the mounting bolts of the motor (or machine) and to experiment with variations in position while the set is in operation.

Changes in degree of noise or vibration will guide your efforts until the set is in line and the symptom disappears.

Where a level shows a motor to be off-level, this condition can be corrected by placing shims under the motor legs until the units are in line.

Also included under the broad heading of misalignment is excessive tension in belt and chain drivers. Here again, something has to give. Either the drive itself will suffer accelerated wear ... or bearings of the motor or machine will be damaged. To be safe, tension should be no more than adequate.

6. VIBRATION

a. General

One of the great Caruso's favorite displays of vocal power was to hold a water glass in his hand--sing in a sympathetic pitch (high-frequency vibration)--and increase his volume until the glass suddenly shattered. Such is the destructive force of vibration!

As mentioned before, misalignment is one important cause of motor vibration. And there are other causes well worth considering.

Even when alignment is perfect, for example, vibration in the driven machine may be transmitted to the motor.

And careless servicing can put rotors out of balance, motor mounting bolts can work loose, bearings can wear to the point where shaft oscillation of considerable amplitude is permitted. Because the vibration resulting from such conditions can shake motor parts and electrical connections loose, crystallize metals and multiply frictional wear, excessive vibration should always be tracked down and its cause eradicated.

b. How to Fight Vibration

Often, the source of vibration must be located by a process of elimination--checking points in this order unless otherwise indicated (proper alignment is assumed):

(1) Tighten all mounting bolts; check motor for loose parts.

(2) For solidity, compare foundation with that of non-vibrating motors. Further improvement of conditions leading to vibration may be unnecessary--or useless!

(3) Check bearings for looseness. Generally, allow two thousandths of an inch clearance--plus one thousandth of an ince for each inch or fraction of an inch of journal diameter.

(4) Disengage vibrating motor from driven machine. If motor operates far more smoothly when disconnected (proper alignment is assumed), then the machine should be examined for sources of vibration.

(5) If vibration trouble should seem to date back to its repair, check rotor for balance--dynamic balance, if possible; otherwise static.

Capscrew the needed weight to point of unbalance--hooking weight around part of motor to relieve pull on screw.

Vibration isn't always easy to eliminate, but everything done to fight it is important in keeping your motors on the job.

7. UNEVEN WEAR

a. General

On slip rings and commutators of electric motors, wear is accepted as inevitable--just as it is on the tires of a car. The reason, of course, is that none of these rotating parts exposed to constant friction can be lubricated with petroleum products.

But just as tire wear can be minimized by switching tires around to keep tread wear even--so the wear on commutators and slip rings can be minimized by preventing conditions leading to "grooving" (concentration of wear in narrow rings or ruts).

On commutators and slip rings--as on tires--smooth and even wear is SLOW wear.

b. How to Fight Uneven Wear

Because dust is an abrasive agent, it should be wiped off the surfaces of slip rings and commutators at regular intervals. (And great care should be taken that a film of oil does not collect on their surfaces--as it both catches dust and prevents proper contact with the brushes.)

If the surfaces of rings or commutators are found to be rough or otherwise uneven, the condition should be remedied at the first opportunity ... before it can invite grooving, pitting, sparking and increasingly accelerated wear.

Often, the best way to smooth a surface is to run the rotor at normal speed in its own bearings. Time is saved, too. By using a commstone in a suitable holder, there is no need to remove rotor, commutator or slip rings.

When commutators are turned down, the mica separating bars should then be relieved to a depth of about one thirty-second of an inch. In fact, mica should always be undercut when high or even level ... to forestall excessive brush wear and sparking.

On the other hand, brushes themselves can contribute to excessive wear. When worn unevenly, they should be trued or replaced with a new set ... before they can damage slip rings or commutator. And to assure maximum, smooth contact, new brushes should be "sanded in" to the proper arc.

If a motor with sleeve bearings and belt drive does not oscillate (the shaft float back and forth axially), a change in alignment may permit this movement. Its advantage is that wear is thus spread over a wider area--kept more even.

By using these various means to keep all surfaces in contact even and smooth, friction and wear can be kept at a minimum.

8. OVERLOAD

a. General

The electric motor driving a production machine is one of your best and most faithful workers. Because there is a temptation to make a good worker produce even more, it should be clearly recognized that overload will cause motors to heat up and eventually break down or burn out.

Motors--like men, horses, bridges, everything--have a breaking point. And while it is common practice among manufactures to rate the capacity of their motors below their particular breaking points, this is sound practice.

The margin of safety thus provided corresponds to the "safety factor" employed in airplane construction (although it is FAR smaller). It should never be narrowed by deliberately making a motor carry too great a mechanical load.

Of course, overloading is not always intentional. Far from it. It can be produced quite accidentally ... by error in application--by obstruction in the drive or driven machine--by excessive friction within the motor itself--or by well-meaning effort to obtain greater output from the driven machine than the motor is capable of carrying.

If one of these conditions causes the current in a motor to exceed its nameplate current rating, heating may increase as much as the square of the current increase. The danger is that insulation will be "fried", soldered connections melted, bearings burned out ... any one or all!

b. How to Fight Overload

To safeguard against such overloads, motors are given various forms of "overload protection". In most cases, a thermal element is connected in the power circuit to the motor. Heat from the element operates an overload relay, opening the circuit to the motor.

But whether the protective unit be thermal element or fuse, it should be of the proper capacity ... as listed in the national code. NEVER EMPLOY A UNIT OF MORE THAN THIS RECOMMENDED VALUE.

That's step number one--to protect the motor. Step number two is to protect continuous production ... by guarding against the conditions that trip or blow the overload protection devices. First things first. Fuses and heater coils are a whole lot cheaper than motors--AND EASIER TO GET!

9. UNDERLOAD

a. General

Although the penalties are less severe, underloading an induction motor is just as clearly improper as overloading it.

As indicated below, the total current flowing in an a. c. circuit is made up of two components: (1) "real (useful) power"--that produces mechanical energy--and (2) "wattless current"--that produces merely the magnetic field required in induction motors.

It is characteristic of induction motors that when they are working under only part load the proportion of the two components in the total power is changed. Real power is DECREASED--the proportion of wattless current is INCREASED.

Technically the "power factor" (ratio of real power to total power) is lowered.

Comparing total or apparent power to a man of a given size, we see that wattless current is like fat--real power, like muscle. The more of one, the less of the other.

And because there is a limit to the power capacity of generators, transformers and power lines, the character or quality of the total power is of prime importance.

Poor quality--a low power factor produced by induction motors worked at underload--has four disadvantages:

(1) Higher line losses; higher voltage drop. Motors lose torque.

(2) Increased load on a utility's lines and equipment--in many cases causing breakdowns and interrupted service which slow down production.

(3) As a frequent result, a higher energy cost to the user.

(4) Motors are apt to overheat due to excessive currents set up by the high proportion of wattless current.

Obviously, underload causes serious inefficiency.*

b. How to Fight Underload

First step in correcting a condition of underload causing low power factor is to take inventory. Determine the rated capacity of each induction motor and its actual load. List these data on a large sheet.

If a plant has been consistenly over-motored, it may be possible to advance most motors, except the largest, to heavier jobs ... replacing the smallest motors with even smaller ones of proper capacity. Such juggling of equipment almost suggests itself once the facts are gathered and organized.

Minimizing underload is the preventive way of improving power factor. Corrective measures include the increased use of synchronous condensers, synchronous motors, and capacitors.

Whatever method or combination you use, improving the power factor of your plant gives you more satisfactory production power and other benefits which accrue directly from the efficient operation of your electric motors.

* It should be noted that in rare cases maximum guarantee of continuous service outweighs other considerations--and an underloaded conditioning may be proper.

11. Diagnois of Motor Ailments

SYMPTOMS YOU CAN SEE

Symptom	Possible Causes	Cure
1. Excessive sparking or flashing at brushes. Blackened commutator.	Rough commutator.	Sand or turn down, depending on depth of surface roughness.
	Low bar on commutator.	Grind or turn down balance of commutator.
	High bar on commutator.	If extreme, lower with mallet ... tightening clamping ring. Grind true.
	High mica.	Undercut.
	Brushes too short.	Replace--with harder grade--if worn too soon ... and not by rough commutator. (Sometimes underloaded brushes wear abnormally fast.) Ordinarily, set should last for a minimum of 2,500 hours.
	Insufficient brush tension.	Adjust.
	Weak brush springs.	Replace.

Symptom	Possible Causes	Cure
	Load too heavy. Disconnect motor to see if it starts without load.	Reduce load--or replace motor with unit of greater capacity.

SYMPTOMS YOU CAN HEAR

Symptom	Possible Causes	Cure
1. Excessive hum.	Uneven air gap. Measure with feelers.	Replace bearings--before introduction of scraping noise indicates rotor is rubbing against stator.
	Unbalanced rotor. Check on parallel bars.	Balance with solder on band--or weight attached by cap screw and lock washer.
2. Regular clicking.	Foreign matter in air gap.	Take out rotor; remove matter.
3. Rapid knocking.	Misalignment--probably causing shoulder of shaft to pound periodically against bearing end.	Realign set until knocking disappears.
4. Brush "chatter".	Extreme motor vibration.	See items 1 and 2 below.

SYMPTOMS YOU CAN FEEL

Symptom	Possible Causes	Cure
1. Vibration.	Misalignment.	Realign set.
	Vibration in driven machine. Run motor disconnected for check.	Eliminate source in machine, if possible. Or change to a flexible belt drive may be in order.

Symptom	Possible Causes	Cure
	Load too heavy. Disconnect motor to see if it starts without load.	Reduce load--or replace motor with unit of greater capacity.

SYMPTOMS YOU CAN HEAR

1. Excessive hum.	Uneven air gap. Measure with feelers.	Replace bearings--before introduction of scraping noise indicates rotor is rubbing against stator.
	Unbalanced rotor. Check on parallel bars.	Balance with solder on band--or weight attached by cap screw and lock washer.
2. Regular clicking.	Foreign matter in air gap.	Take out rotor; remove matter.
3. Rapid knocking.	Misalignment--probably causing shoulder of shaft to pound periodically against bearing end.	Realign set until knocking disappears.
4. Brush "chatter".	Extreme motor vibration.	See items 1 and 2 below.

SYMPTOMS YOU CAN FEEL

1. Vibration.	Misalignment.	Realign set.
	Vibration in driven machine. Run motor disconnected for check.	Eliminate source in machine, if possible. Or change to a flexible belt drive may be in order.

Symptom	Possible Causes	Cure
2. Vibration--following motor repair.	Rotor out of balance, due to holes drilled or weights shifted ... new rotor coil or coils.	Balance rotor.
3. Motor over-heating. (Check with thermometer--don't depend on hand).	Overload. Measure load; compare with nameplate rating.	Check for excessive friction in motor, drive or machine. Reduce load, or replace motor with unit of greater capacity.
	Dirt in motor. Check flow of ventilating air.	Blow out motor. Use solvent on wound section if necessary.
	Rotor rubbing on stator.	Replace bearings.
	Shorted stator windings.	Test with wattmeter and correct.
	Ground.	Locate with test lamp or growler and repair.
4. Bearing over-heating.	Misalignment.	Realign set. And in this--as in all cases of bearings over-heating--keep shaft turning until bearing is cooled ... to prevent "freezing".
	Too much tension in chain or belt drive.	Reduce tension to point of adequacy.

Symptom	Possible Causes	Cure
	Excessive end thrust.	Reduce thrust from drive or machine. (Shaft should be permitted reasonable "axial" float.) Or if motor is off level, shim-up lower end to take thrust off its bearing.
	Too much grease (ball or roller bearing).	Relieve supply to point set by manufacturer.
	Sticking oil ring (sleeve bearing).	Clean, repair, or replace--as necessary.
	Insufficient lubricant.	Add--up to point set by manufacturer.
5. Commutator hot.	Incorrect grade of brushes.	Replace with proper grade--as specified by manufacturer, unless otherwise indicated.
	Excessive brush pressure.	Decrease brush spring tension.

PART VIII

ELECTRICAL MEASURING DEVICES

1. GENERAL

Using electrical test equipment is one of the most useful and important parts of your job as you maintain engineer equipment. During this lesson we will discuss various types of meters and how to use them.

2. TYPES OF METERS

There are basically three types of individual meters used to measure electrical circuits. After we have discussed these basic meters, we will discuss two types of combination or multimeters which combine several meters into one.

a. Ammeter. An ammeter is used to measure the amount of current flowing in a circuit. Because the windings in an ammeter are of very low resistance, the ammeter must always be connected in series with the circuit being tested. Figures 1 and 2 illustrate the correct and incorrect method of using an ammeter.

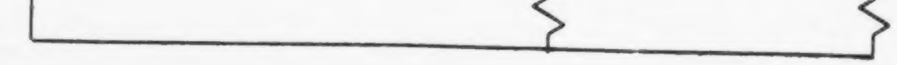


FIGURE 1 - CORRECT USAGE OF AMMETER

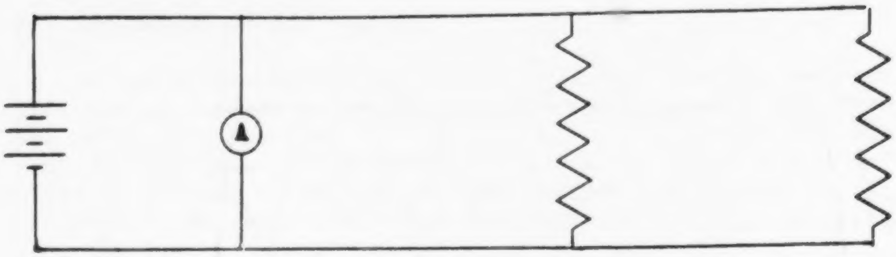


FIGURE 2- INCORRECT USAGE OF AMMETER

b. Voltmeter. A voltmeter is used when measuring for voltage in a circuit. It must be connected in parallel, or across, with a load or resistance. Figure 3 illustrates the correct usage of a voltmeter. CAUTION. When measuring DC voltages the proper polarity must be observed.

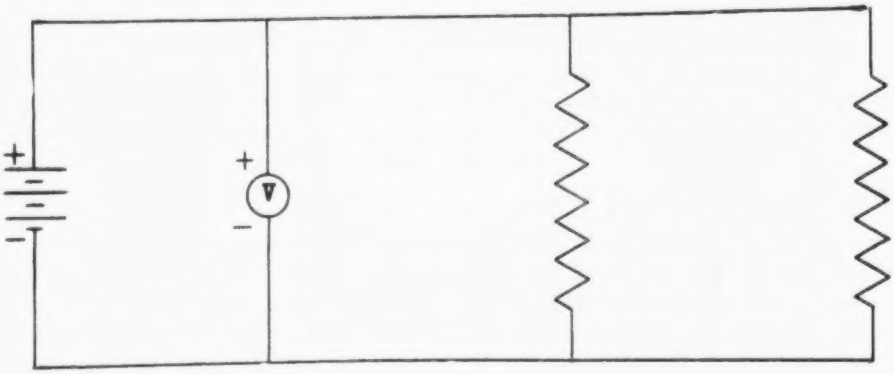


FIGURE 3 - CORRECT USE OF VOLTMETER

c. Ohmmeter. An ohmmeter, of course, is used to measure resistance, but there are a couple of safety procedures to be aware of and to follow. First, be sure all power is off in the circuit. An ohmmeter has its own source of power, and if connected across a live circuit will burn up. Second, the item under test must be isolated. If three resistances are in parallel, and each one has a resistance of 30 , and you try to measure only one your reading will be 10 unless you isolate the individual resistor being measured. Figure 4 shows the proper connecting for an ohmmeter.

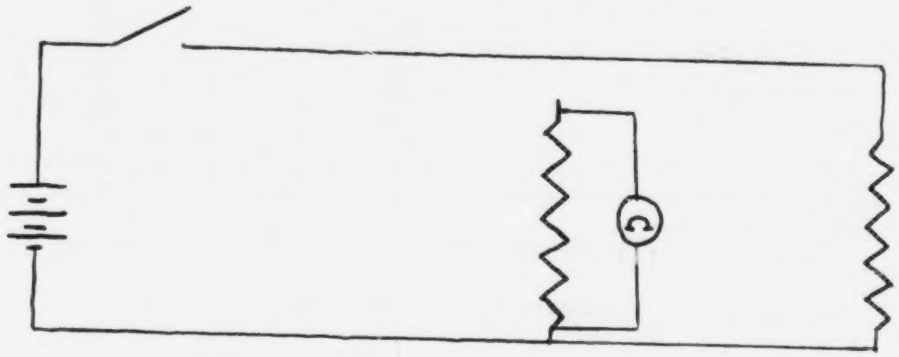


FIGURE 4 - CORRECT CONNECTIONS FOR AN OHMMETER

3. OPERATION OF THE "AMPROBE"

A convenient electrical measuring device used to measure alternating current and voltage is the split-core AC ammeter. The meter is a clamp-on type which instantly measures the current without shutdowns or meter connections. Voltage is measured by the use of test leads that connect the instrument to the load. The meter also reads the resistance. This meter is known as the "amprobe."

When making a voltage test with the "Amprobe", connect the test leads to the terminals on the side of the instrument. Now rotate the selector switch to the highest voltage scale. Connect the test leads to the load and observe the reading, if the reading is well within the range of the next lower scale, switch to this scale by rotating the selector switch.

For measuring AC current, these test leads are not needed. The meter uses a set of jaws that are clamped around a single conductor under test. Since there is an alternating current flowing through the conductor there is also an alternating magnetic field around the conductor. The intensity of magnetic field is proportional to the amount of current flowing into the jaws of the instrument and thus the amount of current in the conductor is determined.

In order to measure AC current, set the selector switch to the highest ampere scale, squeeze on the trigger mechanism to open the jaws, and then release the trigger to close the jaws around the conductor under test. If the reading is within the range of the next lower scale, revolve the selector switch to a lower scale.

Since there are two scales on the instrument, it is sometimes difficult for a student to determine which scale to read. On this meter, voltage readings are color coded red and current is colored black. Also, the scales have several sets of numbers under each subdivision. In order to determine which number to read, note the position of the selector switch. The highest number on the scale to read will be the same or a multiple of ten of the selector switch number.

VOLTS
AMPROBE
VOLT-AMMETER

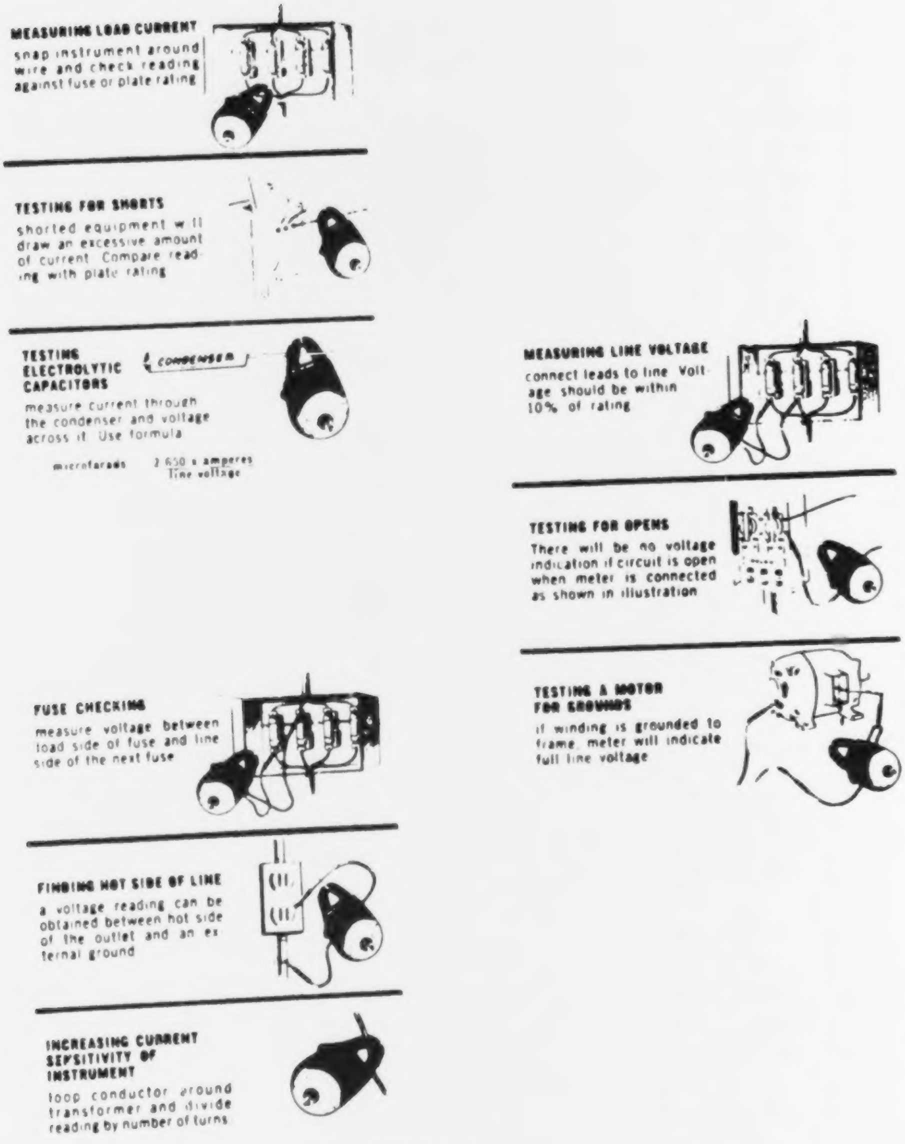
Amprobe "300"

MODEL	SPECIFICATIONS
300	**6 AMMETER RANGES**: 0-6/15/30/60/150/300 Amps AC **3 VOLTAGE RANGES**: 0-150/300/600 Volts AC **CONDUCTOR CAPACITY**: 1⅜" diameter, handle bars up to ½" x 1½" **WEIGHT**: 13 oz **DIMENSIONS**: 1¼" thick, 2⅝" wide 8" long **SCALE LENGTH**: 2.363 inches
600	**6 AMMETER RANGES**: 0-15/30/60/150/300/600 Amps AC **3 VOLTAGE RANGES**: 0-150/300/600 Volts AC **CONDUCTOR CAPACITY**: 2" **WEIGHT**: 15 oz **DIMENSIONS**: 2⅝" wide 1¼" thick 8½" long **SCALE LENGTH**: 2.363 inches Exclusive doughnut-type transformer
1200	**6 AMMETER RANGES**: 0-15/60/150/300/600/1200 Amps AC **3 VOLTAGE RANGES**: 0-150/300/600 Volts AC **CONDUCTOR CAPACITY**: 2" **WEIGHT**: 15 oz **DIMENSIONS**: 2⅝" wide 1¼" thick, 8½" long **SCALE LENGTH**: 2.363 inches Exclusive doughnut type transformer

		1 AMMETER RANGE	2 VOLTMETER RANGES	
AMPROBE JUNIOR (Choose the model that fits your job)	MODEL "525"	0-25 amps A.C.	0-150/600 volts A.C.	**CONDUCTOR CAPACITY**: ½" **WEIGHT**: 11 oz **DIMENSIONS**: Body: 2½" wide 4¾" long, 1⅜" thick **SCALE LENGTH**: 1.8 inches
	MODEL "550"	0-50 amps A.C.	0-150/600 volts A.C.	
	MODEL "500"	0-100 amps A.C.	0-150/600 volts A.C.	
	MODEL "10"	0-10 amps A.C.	0-125/250 volts A.C.	
	MODEL "25"	0-25 amps A.C.	0-125/250 volts A.C.	
	MODEL "50"	0-50 amps A.C.	0-125/150 volts A.C.	
	MODEL "100"	0-100 amps A.C.	0-125/150 volts A.C.	

FIGURE 5

The ideal Amprobe model for general, all around work. Covers 6 ammeter ranges up to 300 amps, and 3 voltmeter ranges up to 600 volts AC. The tapered probe jaws are perfect for "hard-to-get-at" wires in crowded switch boxes. Comes with voltage test leads and top grain cowhide leather case.



MEASURING LOAD CURRENT

snap instrument around wire and check reading against fuse or plate rating

TESTING FOR SHORTS

shorted equipment will draw an excessive amount of current. Compare reading with plate rating

TESTING ELECTROLYTIC CAPACITORS

measure current through the condenser and voltage across it. Use formula

$$\text{microfarads} \quad \frac{2\,650 \times \text{amperes}}{\text{line voltage}}$$

FUSE CHECKING

measure voltage between load side of fuse and line side of the next fuse

FINDING HOT SIDE OF LINE

a voltage reading can be obtained between hot side of the outlet and an external ground

INCREASING CURRENT SEPSITIVITY OF INSTRUMENT

loop conductor around transformer and divide reading by number of turns

MEASURING LINE VOLTAGE

connect leads to line. Voltage should be within 10% of rating

TESTING FOR OPENS

There will be no voltage indication if circuit is open when meter is connected as shown in illustration

TESTING A MOTOR FOR GROUNDS

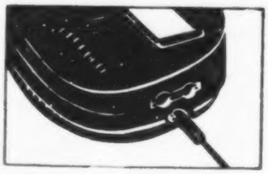
if winding is grounded to frame, meter will indicate full line voltage

FIGURE 6

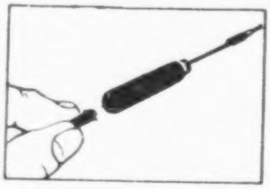
Uses of Amprobe "300"

HOW TO USE THE AMPROBE AS AN OHMMETER

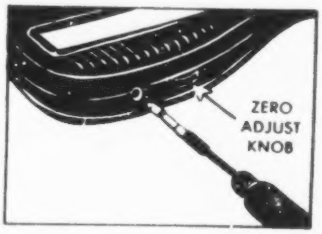
1. Insert either the red or black voltage lead into the **LEFT** VOLTAGE RECEPTACLE at bottom of Amprobe case.



2. Insert the other voltage lead into the bottom of the Battery Case. Push in and twist to lock in place.



3. Plug the battery case into the jack on the right side of the Amprobe just below the ohmmeter Zero Adjust Knob. Seat plug to bottom for good connection.



4. **SET RANGE SELECTOR SO THAT THE 150 VOLT RED SCALE APPEARS IN WINDOW.**

5. **OHMMETER SCALE ADJUSTMENT WITH TEST LEADS OPEN**—Pointer should line up with division marked " oo " on OHMS SCALE. Turn pointer zero adjust screw if necessary.

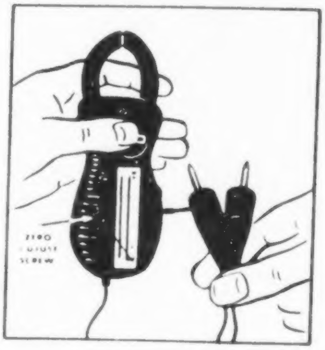
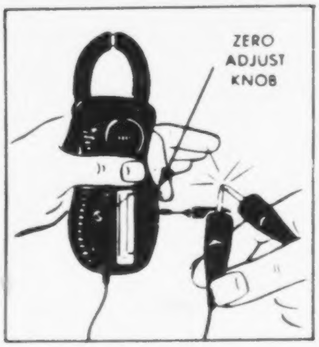


FIGURE 7

HOW TO USE THE AMPROBE AS AN OHMMETER

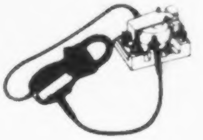
WITH TEST LEADS SHORTED—Line up pointer with "O" mark on ohms scale by turning small black knob on right side of Amprobe



NOTE: If ohmmeter zero adjust knob does not line pointer up on zero mark, replace battery with a new one.

6. TO MEASURE RESISTANCE between any two points on a device, apply clip leads and read pointer on ohms scale.

   CAUTION - Make certain that circuit is disconnected from line before taking any resistance measurements.



How To Read Ohmmeter Scale.

The ohmmeter scale is located on the flat plate to the right of the window. The zero mark (beginning) is on top of the scale while the infinity mark "oo" ends the scale.

HOW TO REPLACE BATTERY

Twist knurled button attached to spring loaded wire assembly and remove from battery case. Turn battery case upside down and battery will fall out. Replace battery by inserting positive side first into battery case. Spring is then inserted against negative side followed by knurled button and wire. USE EVEREADY # 912 OR EQUAL.

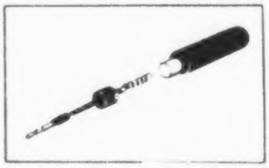
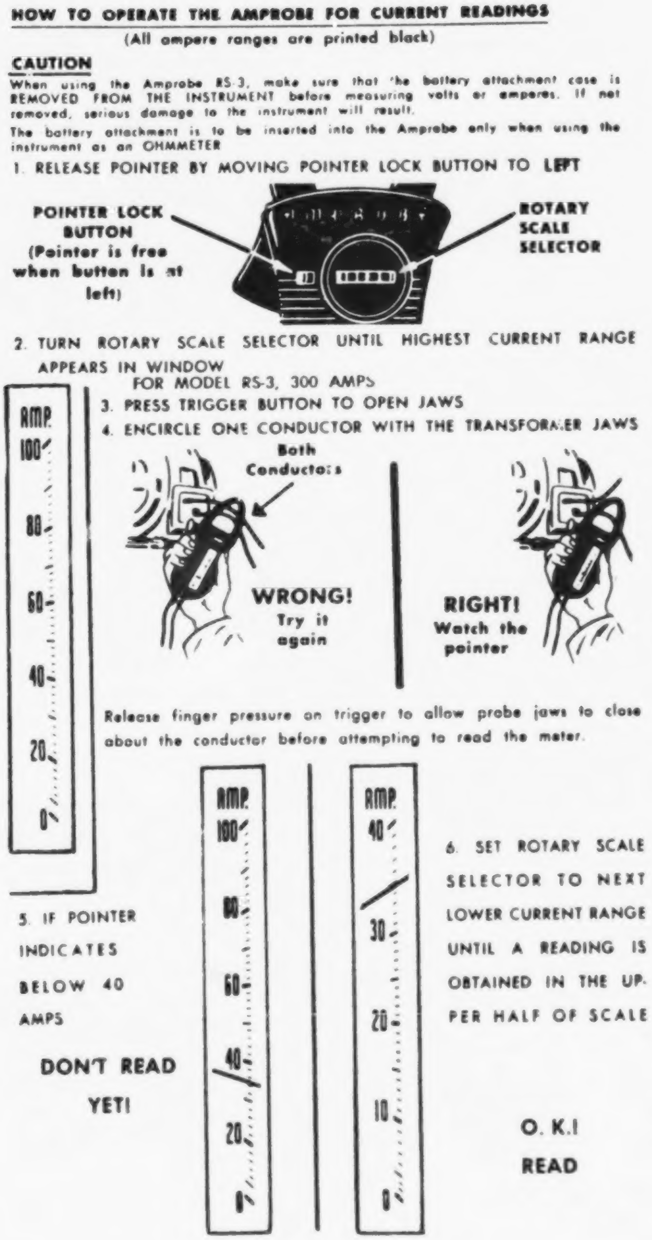


FIGURE 8



HOW TO OPERATE THE AMPROBE FOR CURRENT READINGS

(All ampere ranges are printed black)

CAUTION

When using the Amprobe RS-3, make sure that the battery attachment case is REMOVED FROM THE INSTRUMENT before measuring volts or amperes. If not removed, serious damage to the instrument will result.

The battery attachment is to be inserted into the Amprobe only when using the instrument as an OHMMETER

1. RELEASE POINTER BY MOVING POINTER LOCK BUTTON TO LEFT

POINTER LOCK BUTTON (Pointer is free when button is at left)

ROTARY SCALE SELECTOR

2. TURN ROTARY SCALE SELECTOR UNTIL HIGHEST CURRENT RANGE APPEARS IN WINDOW FOR MODEL RS-3, 300 AMPS
3. PRESS TRIGGER BUTTON TO OPEN JAWS
4. ENCIRCLE ONE CONDUCTOR WITH THE TRANSFORMER JAWS

Both Conductors

WRONG! Try it again

RIGHT! Watch the pointer

Release finger pressure on trigger to allow probe jaws to close about the conductor before attempting to read the meter.

5. IF POINTER INDICATES BELOW 40 AMPS

DON'T READ YET!

6. SET ROTARY SCALE SELECTOR TO NEXT LOWER CURRENT RANGE UNTIL A READING IS OBTAINED IN THE UPPER HALF OF SCALE

O. K.! READ

FIGURE 9

How To Operate The Amprobe for Current Readings (cont'd)

6. IF THE READING IS BELOW HALF SCALE ON THE LOWEST RANGE OF THE METER, AND GREATER ACCURACY IS DESIRED, THE FOLLOWING METHOD CAN BE USED.

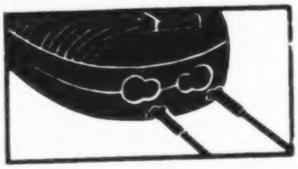
Loop the conductor two or more times around the transformer jaws and divide the reading by the number of turns.

(All voltage ranges are printed red)

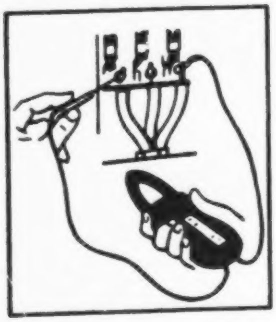
CAUTION

When using the Amprobe RS-3, make sure that the battery attachment case is REMOVED FROM THE INSTRUMENT before measuring volts or amperes. If not removed, serious damage to the instrument will result.

The battery attachment is to be inserted into the Amprobe only when using the instrument as an OHMMETER



1. INSERT SAFETY BAYONET TYPE VOLTAGE TEST LEADS INTO VOLTAGE RECEPTACLES AT BOTTOM OF AMPROBE. PUSH AGAINST RECEPTACLE SPRING AND TWIST TO LOCK IN PLACE.
2. TURN ROTARY SCALE SELECTOR UNTIL HIGHEST VOLTAGE RANGE — 600 VOLTS—APPEARS IN WINDOW.
3. CONNECT ONE ALLIGATOR CLIP TO ONE SIDE OF LINE. THEN WITH METER IN ONE HAND TOUCH THE OTHER SIDE OF THE LINE WITH THE ALLIGATOR CLIP. IF VOLTAGE DOES NOT EXCEED 600 VOLTS ATTACH SECOND ALLIGATOR CLIP AND READ VOLTAGE ON RED SCALE MARKED 600 VOLTS.

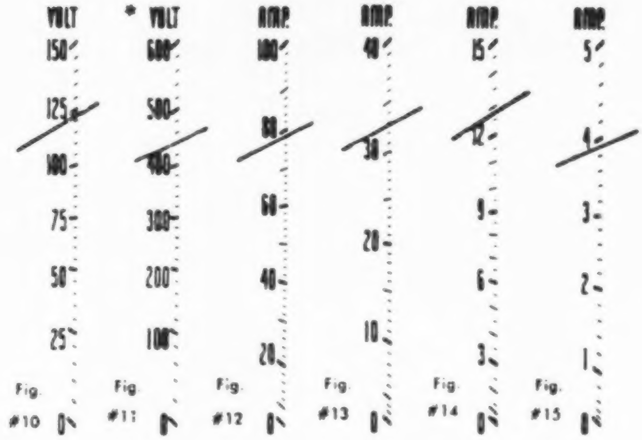


4. IF VOLTAGE IS BELOW 150, ROTATE SCALE SELECTOR UNTIL THE 150 VOLT RANGE APPEARS IN WINDOW. READ ON THIS SCALE.

FIGURE 10

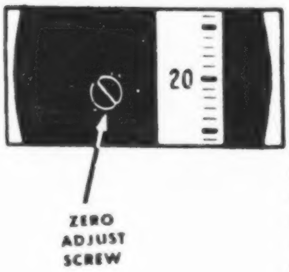
HOW TO READ THE SCALE

Let us assume the pointer is at the position indicated in the illustrations. The reading will be as follows, depending on the setting of the range selector—


VOLT
150
125
100
75
50
25
Fig. #10 0
* VOLT
600
500
400
300
200
100
Fig. #11 0
AMP
100
80
60
40
20
Fig. #12 0
AMP
40
30
20
10
Fig. #13 0
AMP
15
12
9
6
3
Fig. #14 0
AMP
5
4
3
2
1
Fig. #15 0

POINTER READS 122.5 VOLTS	POINTER READS 440 VOLTS	POINTER READS 78 AMPS	POINTER READS 32.5 AMPS	POINTER READS 12.7 AMPS	POINTER READS 3.9 AMPS
Each subdivision between 100 & 150 is 5 volts	Each subdivision between 400 & 500 is 20 volts	Heavy mark between 60 & 80 is 70 Amps. Each sub-division between 70 & 80 is 2 amps	Each subdivision between 30 & 40 is 1 amp	Heavy mark above 12 is 13 amps. Each subdivision between 12 & 13 is .5 amp.	Each subdivision between 3 & 4 is .2 amp

ZERO ADJUSTMENT


20
ZERO
ADJUST
SCREW

FOR GREATEST ACCURACY, THE POINTER SHOULD BE SET EXACTLY ON THE ZERO LINE. THIS IS DONE WITH ZERO ADJUST SCREW.

If while turning the zero adjust screw, the pointed swings away from the zero line, and will not come to rest directly over it, it is possible that the scale window is statically charged. To neutralize—fog the window, just as you would in cleaning eye-glasses.

FIGURE 11

4. MULTIMETER TS/352

The multimeter TS/352 is another convenient electrical test device. It can be used to measure DC voltage, DC current, AC voltage and Resistance. However, it cannot be used to measure AC current.

The red and black test leads are contained in the cover of the multimeter. On the rear of the body of the multimeter there is a cover which is held in place by two screws. Behind the covers are four batteries which are used when measuring for resistance. Refer to Figure 12 and the face of the meter will be explained.

a. Jacks. These jacks are the holes into which the black and red test leads are placed when using the meter.

b. Dial. These scales are where all readings are made.

c. Function Switch. The position of this switch is determined by what the meter is being used to measure. For instance, when measuring resistance the function switch would be in the Ohm's position.

d. Zero Adjust Knob. This is used only when reading resistance.

e. Range Selector Switch. This switch is used when measuring resistance and amperage.

f. Case Ground. This is for use to ground the meter to protect against the danger of electrical shock.

5. SET UPS FOR THE MULTIMETER TS/352

a. Resistance. The first set up for the TS/352 will be for measuring resistance. Refer to Figure 13. The red and black leads must first be placed in their correct positions. The black lead is always placed in the common jack (1). It is referred to as the "common jack" because it is common to all uses of the meter. The red lead is then placed in the Ohm's Jack beside the common jack (2). The Function Switch is placed in the Ohm's position (3). The Selector Switch, lower right hand corner, is ued, and can be set in any of the R x positions although when measuring any unknown valves it is wise to always start with the highest valve (4). Now refer to the dial of the meter (5). The dashed line represents the position of the pointer

MULTIMETER

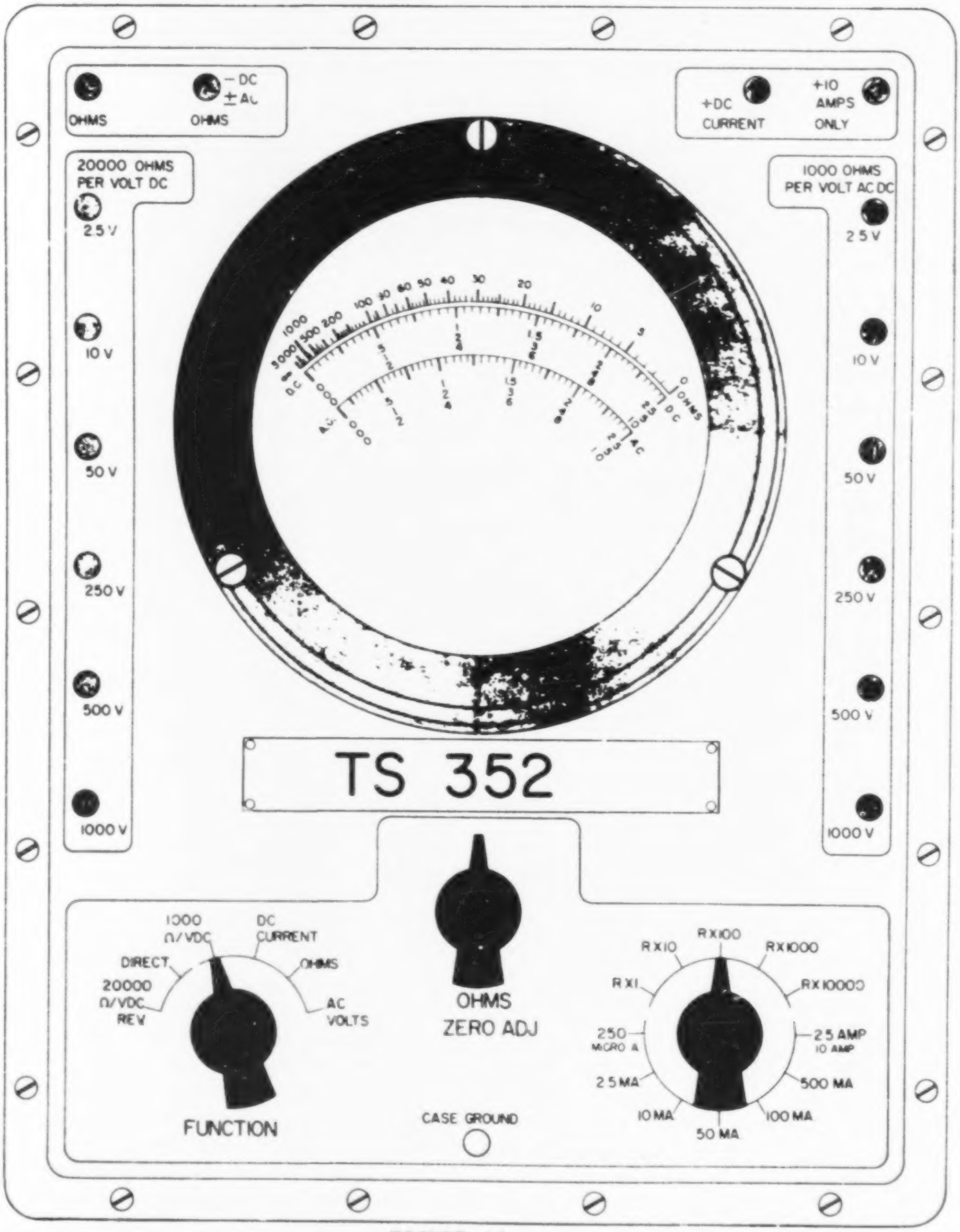

OHMS
− DC
± AC
OHMS
+DC
CURRENT
+10
AMPS
ONLY
20000 OHMS
PER VOLT DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
1000 OHMS
PER VOLT AC DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
OHMS
DC
AC
TS 352
FUNCTION
1000
Ω/VDC
DC
CURRENT
OHMS
AC
VOLTS
DIRECT
20000
Ω/VDC
REV
OHMS
ZERO ADJ
CASE GROUND
RX1
RX10
RX100
RX1000
RX10000
250
MICRO A
2.5 MA
10 MA
50 MA
100 MA
500 MA
2.5 AMP
10 AMP

FIGURE 12

MULTIMETER

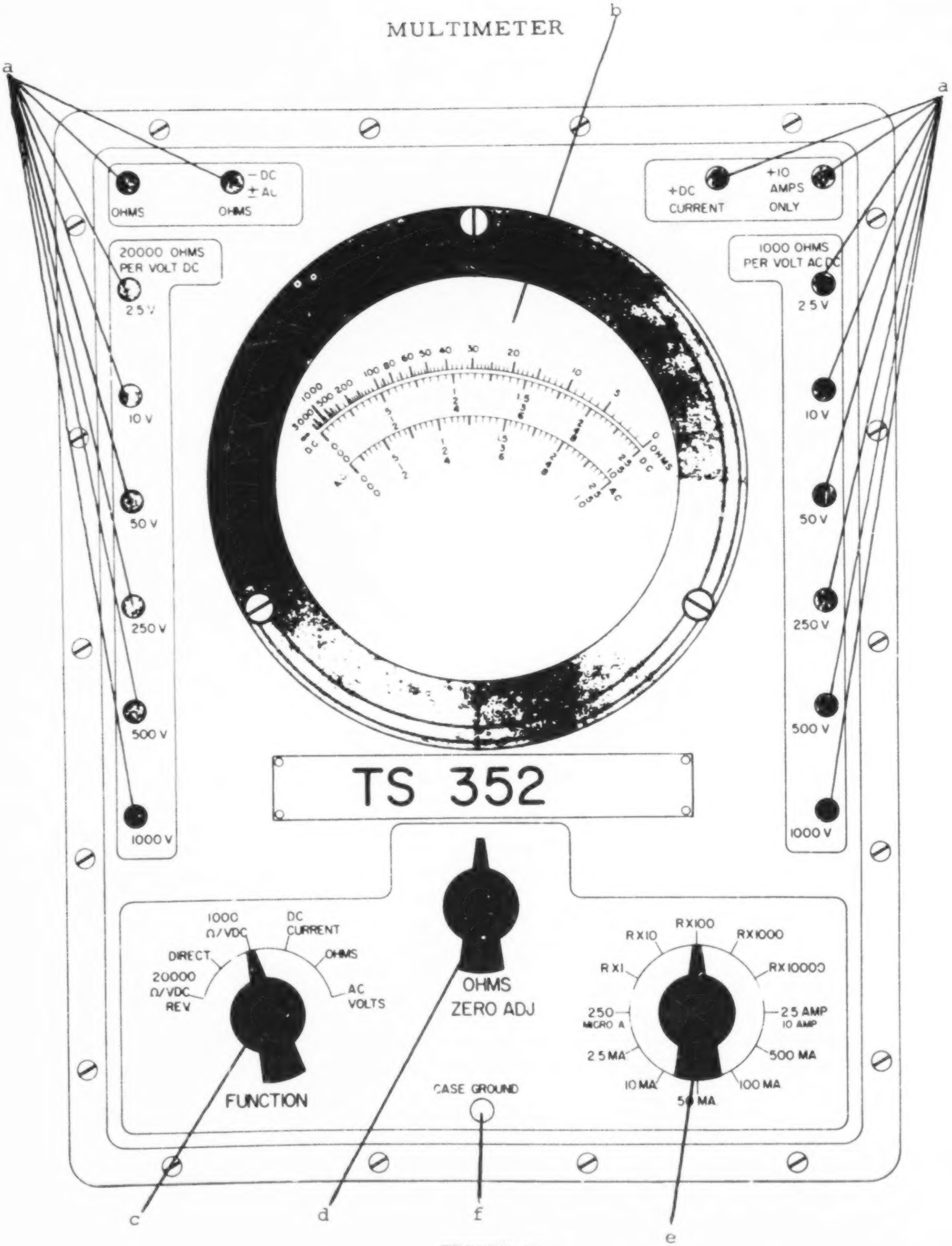

a
b
a
OHMS
OHMS
− DC
± AC
+DC
CURRENT
+10
AMPS
ONLY
20000 OHMS
PER VOLT DC
1000 OHMS
PER VOLT AC DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
DC
AC
OHMS
TS 352
FUNCTION
1000
Ω/VDC
DC
CURRENT
DIRECT
OHMS
20000
Ω/VDC
REV
AC
VOLTS
OHMS
ZERO ADJ
RX100
RX10
RX1000
RX1
RX10000
250
MICRO A
2.5 AMP
10 AMP
2.5 MA
500 MA
10 MA
100 MA
50 MA
CASE GROUND
c
d
f
e

FIGURE 13

when when the meter is not in use. When the red and black leads are touched together the pointer will move to the right as indicated by the dark line. When the leads are touched in this way you can tell the condition of the batteries in each of the range positions R x 1 thru R x 10,000, The meter is always zeroed when the range switch is moved to a new position.

The reading for resistance is always read from right to left on the top scale of the dial. When the range selector switch is in the R x 100, as shown in Figure 13, and the pointer indicates 10 ohms on the dial, the reading of 10 must be multiplied by the range switch setting. In this case, it will be 10 x 100, or the resistance is actively 1000 ohms. The reading must be multiplied by the valve indicated by the range selector switch. Always select the position of the range selector switch which will allow for the last possible reading on the dial which is on the 0-50 section of the scale.

There are two safety precautions to observe when checking resistance. First, turn off the power. This can be done because the Ohmmeter has its own battery power supply. Second, the component being checked must be isolated from the rest of the circuit.

b. DC Voltage. The second set up we will discuss is to measure DC volts. Refer to Figure 14. The black lead is again placed in the common jack (1). The red lead is then placed in the 1000 V jack on the left side of the meter (2). This jack is used when the valve being measured is unknown to protect the equipment. The function switch is then placed in the Direct Position (3). We do not use the zero adjust and range selector switch are not used when measuring DC volts. The readings are then taken reading from left to right on the center scale of the dial (4). The position of the red lead in the jacks (5) will determine the range of the scale to be used. When reading from 2.5 and 10 jacks simply read from the corresponding scale. When reading from the 50, 250, 500 or 1000 jacks simply add the correct number of zeroes to the corresponding scale. Correct polarity must be observed or the meter will read backwards. If this happens polarity can be corrected by either moving the Function Switch to the Rev position or simply switching the leads.

MULTIMETER

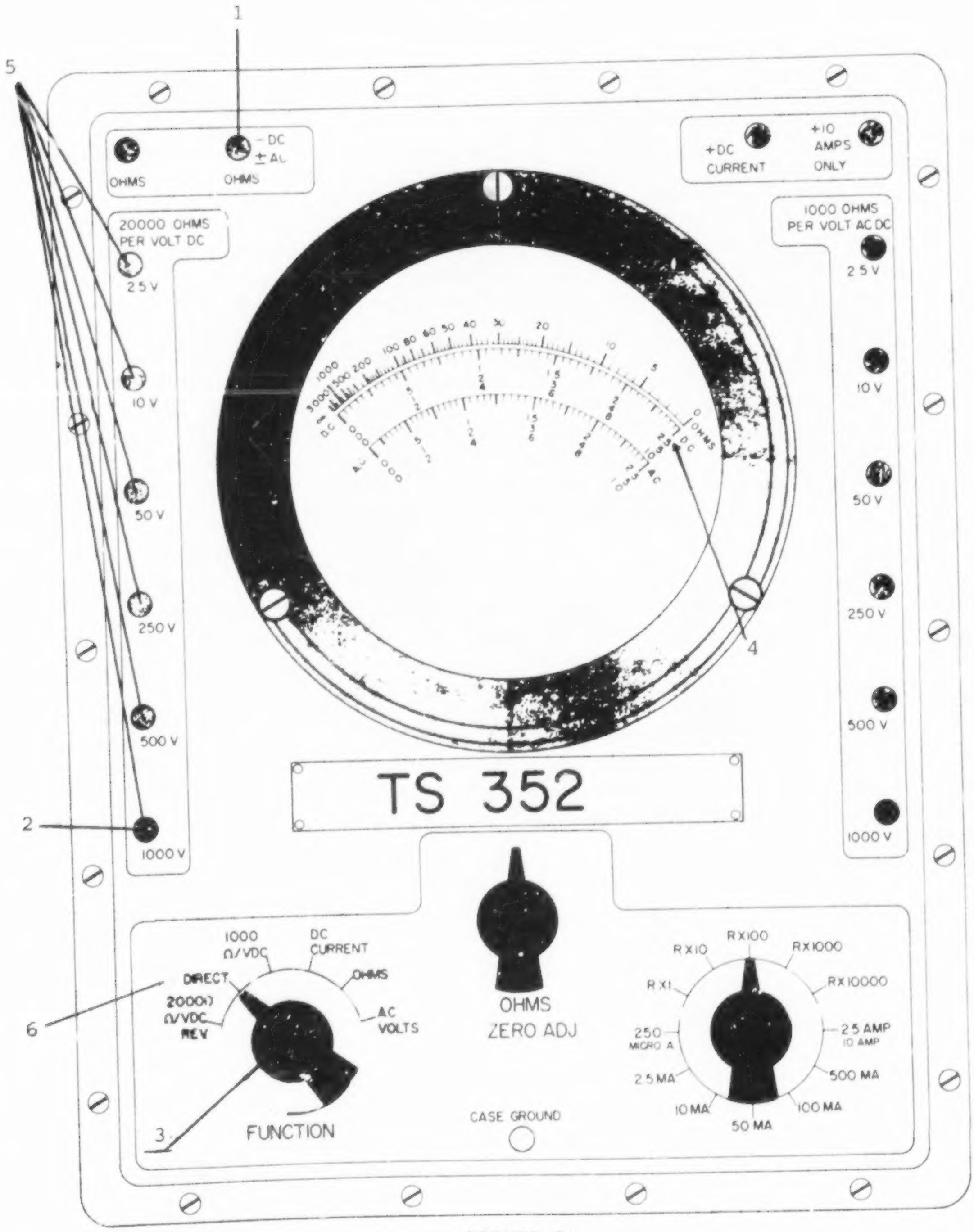

1
5
OHMS
− DC
± AC
OHMS
+DC
CURRENT
+10
AMPS
ONLY
20000 OHMS
PER VOLT DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
1000 OHMS
PER VOLT AC DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
DC
AC
OHMS
4
TS 352
2
1000
Ω/VDC
DC
CURRENT
DIRECT
OHMS
20000
Ω/VDC
REV
AC
VOLTS
6
3
FUNCTION
OHMS
ZERO ADJ
CASE GROUND
RX1
RX10
RX100
RX1000
RX10000
250
MICRO A
2.5 AMP
10 AMP
2.5 MA
500 MA
10 MA
50 MA
100 MA

FIGURE 14

c. DC Current. The third set up we will discuss is for DC current. Refer to Figure 15. Once again we begin by inserting the black lead in the common jack (1), with the red lead to be placed in the +10 amps only jack at the upper right hand corner of the meter (2). The function switch, naturally, will be placed in the DC current position (3), and the range selector switch is positioned in the 2.5 and 10 amp position (4). The readings will be taken from the center scale (the same one we used for DC Volts) of the dial (5). The highest possible DC amperage this meter can read is 10 Amps. With the red lead in position 2 we can accurately measure from 0-10 amps reading on the 10 scale of the dial. If the amperage is less than 2.5 A then a more accurate reading can be made by moving the red lead to position 6 (marked simply + DC current), and reading from the 2.5 A scale. For smaller amounts of current the function switch can be moved to any position from 2.5 to 10A - 250 micro amps. These are minute amounts and generally not used.

d. AC Voltage. Finally, the multimeter TS/352 can be used to measure AC voltage as set up in Figure 16. With the black lead again in the common jack (1), and with an unknown voltage, the red lead is placed in the 1000 V jack on the right side of the meter (2). AC Volts (3) is the position for the function switch, and, once again, we can forget the zero adjust and range selector switch. AC voltage readings are taken on the bottom scale of the dial (4), and the position of the red lead in the various jacks (2.5 - 1000 V) will determine which scale will be used. To read the AC voltage you follow the same procedure as you did when measuring DC volts.

MULTIMETER

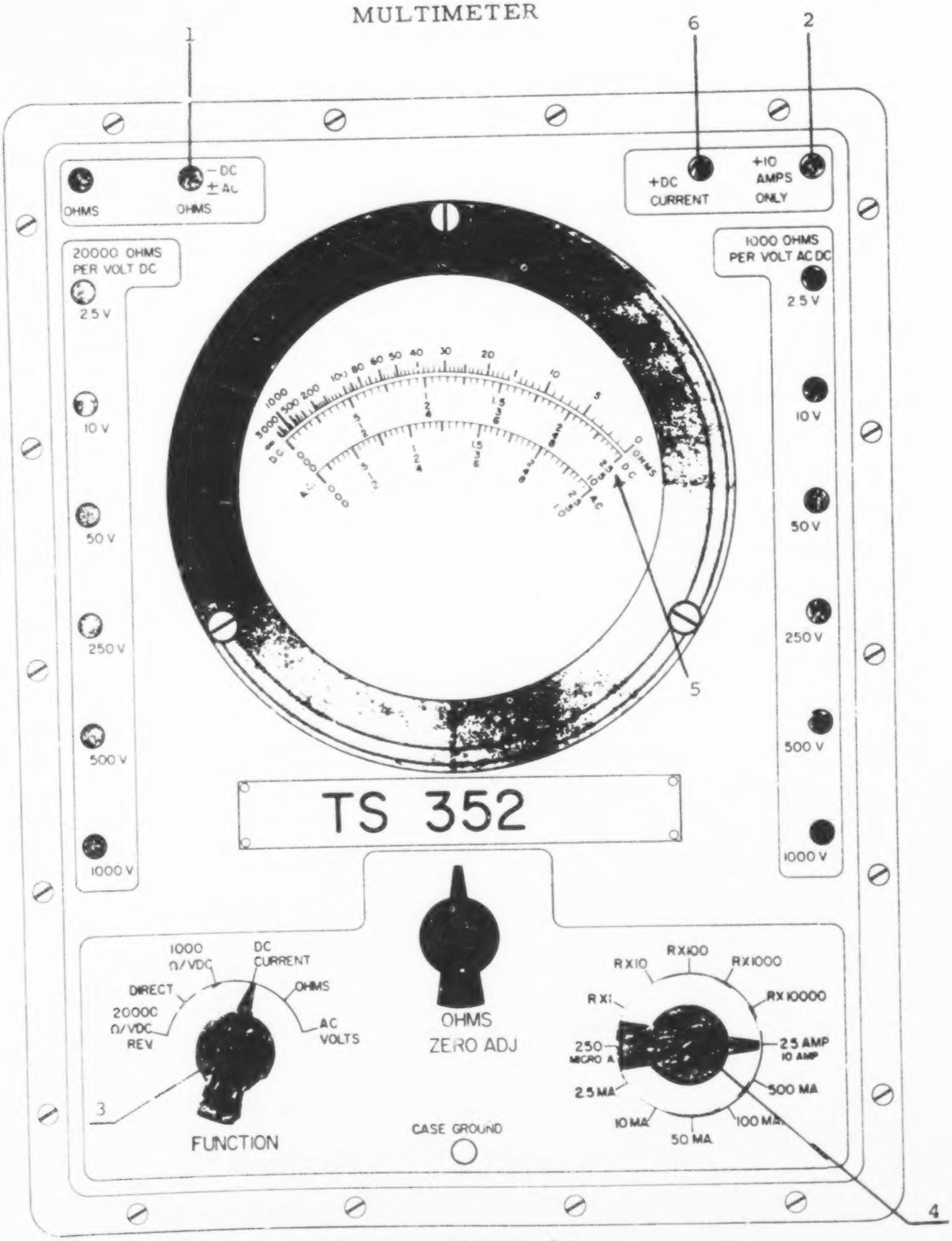

1
6
2
OHMS
OHMS
- DC
± AC
+DC CURRENT
+10 AMPS ONLY
20000 OHMS PER VOLT DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
1000 OHMS PER VOLT AC DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
OHMS
DC
AC
5
TS 352
FUNCTION
20000 Ω/VDC REV
DIRECT
1000 Ω/VDC
DC CURRENT
OHMS
AC VOLTS
3
OHMS ZERO ADJ
CASE GROUND
RX1
RX10
RX100
RX1000
RX10000
2.5 AMP 10 AMP
500 MA
100 MA
50 MA
10 MA
2.5 MA
250 MICRO A
4

FIGURE 15

MULTIMETER

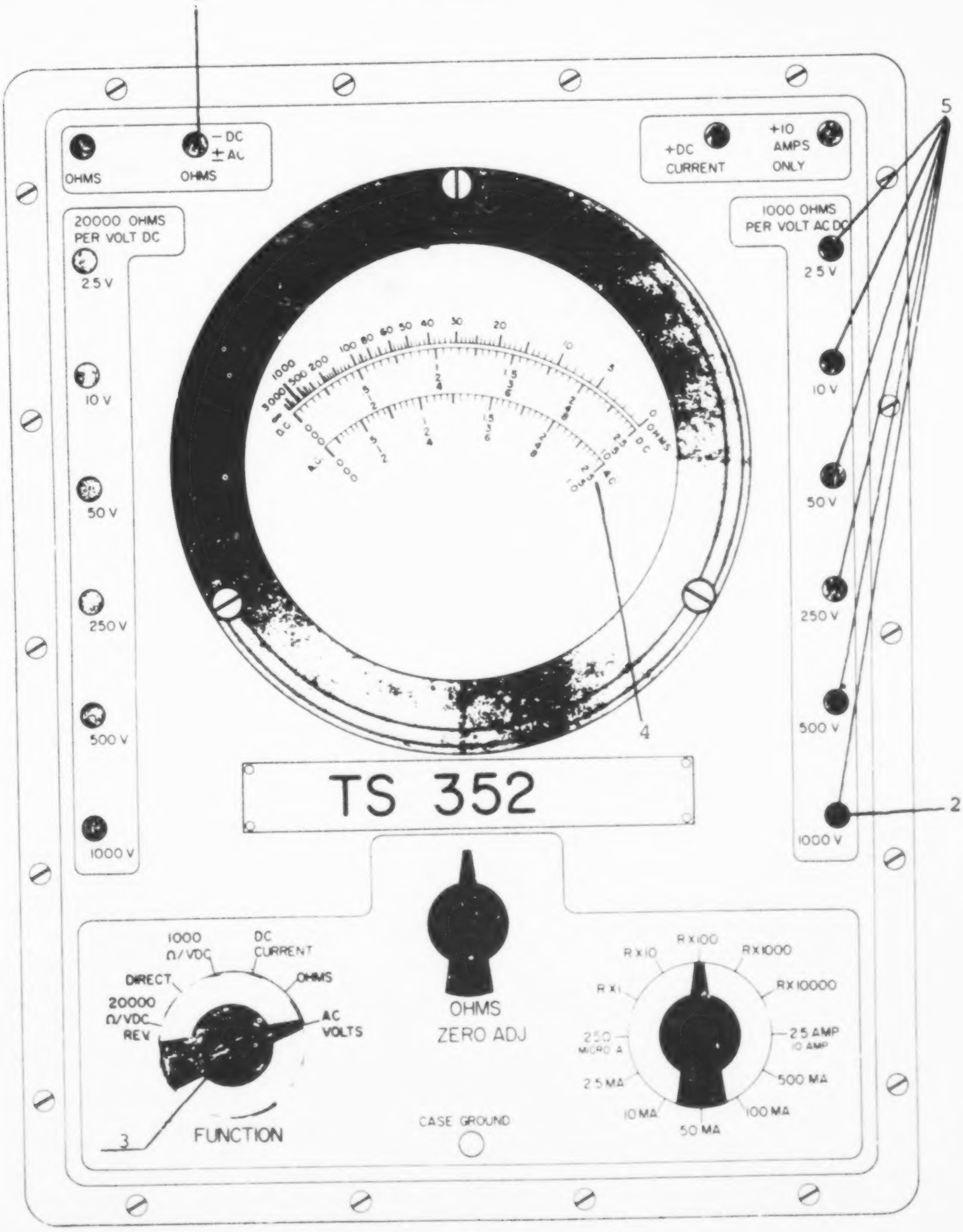

1
OHMS
− DC
± AC
OHMS
+DC
CURRENT
+10
AMPS
ONLY
5
20000 OHMS
PER VOLT DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
1000 OHMS
PER VOLT AC DC
2.5 V
10 V
50 V
250 V
500 V
1000 V
2
OHMS
D.C.
A.C.
4
TS 352
1000
Ω/VDC
DC
CURRENT
DIRECT
OHMS
20000
Ω/VDC
REV
AC
VOLTS
FUNCTION
3
OHMS
ZERO ADJ
CASE GROUND
R X 10
R X 100
R X 1000
R X 1
R X 10000
250
MICRO A
2.5 AMP
10 AMP
2.5 MA
500 MA
10 MA
100 MA
50 MA

FIGURE 16

STUDY QUESTIONS:

1. Why must an ammeter be connected in series?

2. What two precautions must be taken when measuring resistance?

3. What can the amprobe measure?

4. What can the multimeter TS/352 measure?

STUDENT NOTES:

1. TYPES OF METERS

2. AMPROBE

3. MULTIMETER TS/352